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THE AMOUNT AND DISTRIBUTION OF SEISMIC AND GRAVITY EXPLORATION IN THE GULF COAST THROUGH 1936[1]

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ABSTRACT

Maps are presented to show the accumulated density of exploration by the reflection seismograph and the torsion balance for one hundred fourteen counties and parishes comprising the Gulf Coasts of Texas and Louisiana.

The conclusion is drawn that the conspicuous overruns of exploration for these two methods indicated by this survey are a natural consequence of complete surveys for this area by these companies exploring on a coastwide scale. These coastwide coverages represent prospect discovery by the method in question, and are considered to be good practice in view of the probable introduction of new methods of higher finding power.

In a recent paper[3] one of us has called attention to the fact that blanket exploration by the seismograph and the torsion balance is now the general rule in the Gulf Coast. On the basis of this the prediction was made that if no new methods of exploration were introduced into the Gulf Coast in the near future, the volume of exploration by these two methods should soon start to decrease. With a view to examining these predictions, we have conducted a detailed examination of the geophysical scout information collected since July 1930, for the purpose of making a detailed examination of the exploration, county by county and parish by parish, to see if the conclusions drawn for the Gulf Coast as a whole are valid for individual counties and parishes. It was also our hope to include in the report data on the extent to which the law of diminishing returns has run its course for individual counties and parishes, but, unfortunately, the task of as-

[1] Presented at the Mid-Year Meeting, November 20, 1936, Houston Texas.

[2] Independent Exploration Company, Houston, Texas.

[3] On the Strategy and Tactics of Exploration for Petroleum, Jour. Soc. Pet. Geoph. VI, 1, 1935, pp. 11–26.

sembling and organizing the scout data alone has occupied practically the full time of the junior author for six months, and so no start has been made on the analysis of dry holes and discoveries which should form a logical and pertinent part of this report.

To prepare this data, the weekly geophysical scout reports have been analyzed and graphed to show the number of crews operating in each county or parish since July 1930. One hundred and fourteen counties and parishes have been included in this report (cf. Fig. 1), and while they are more than are generally considered as comprising the Gulf Coast province, still the addition of zones of production up dip, like the Cockfield and Saline Bayou, and with the Wilcox threatening, bid fair to justify, in the future at least, the scope of this analysis. The choice of this group of counties and parishes is at least justified to the extent that they are all susceptible to the seismic methods of exploration developed for the Gulf Coast, and, as will be shown later, many of them have hardly been tested sufficiently by gravity methods for proper judgment to be passed as to their suitability for test by that method.

For convenience, the crew year was chosen as the unit of measurement. Crew weeks, of course, were available directly from the scout report. The total number of crew weeks divided by fifty-two gave the number of crew years. For coverage, we assumed that one seismic party averaging half the time on reconnaissance, and half the time on detail, would survey 1250 square miles per year. Mr. J. C. Pollard, of the Magnolia Production Company, kindly furnished the corresponding figure of 500 square miles per year for a torsion balance crew. We recognize, of course, that these estimates of coverage have all the disadvantages of averages, that they may greatly underestimate the performance of individual crews under favorable conditions, and may promise too much for the same crews in unfavorable conditions.

Totals for the whole area under analysis follow:

Total counties and parishes analyzed	114
Total square miles (from U. S. Census)	95,754
Average number square miles covered by average torsion balance crew per year	500
Number of average crew years required for one torsion balance survey of Gulf Coast	191.5
Total torsion balance crew years recorded since July 1930	141.8
Total complete torsion balance surveys, assuming uniform distribution of effort, calculated for the Gulf Coast since July 1930	0.74
Average number square miles covered by average seismic crew per year	1,250
Number of average crew years required for one seismic survey of Gulf Coast	76.56
Total seismic crew years recorded since July 1930	178.6
Total complete seismic surveys, assuming uniform distribution of effort, calculated for the Gulf Coast since July 1930	2.33

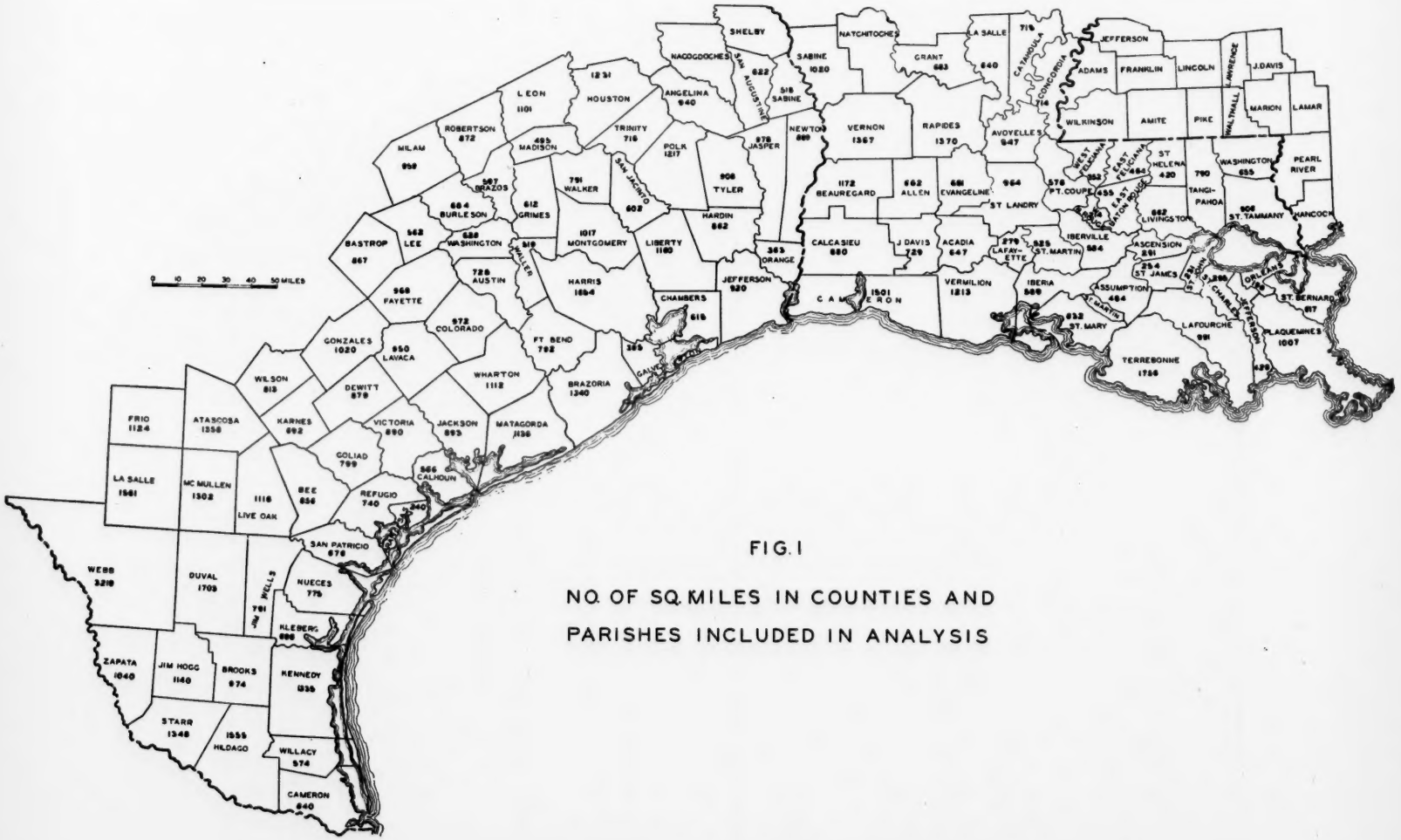


FIG. 1

NO. OF SQ. MILES IN COUNTIES AND PARISHES INCLUDED IN ANALYSIS

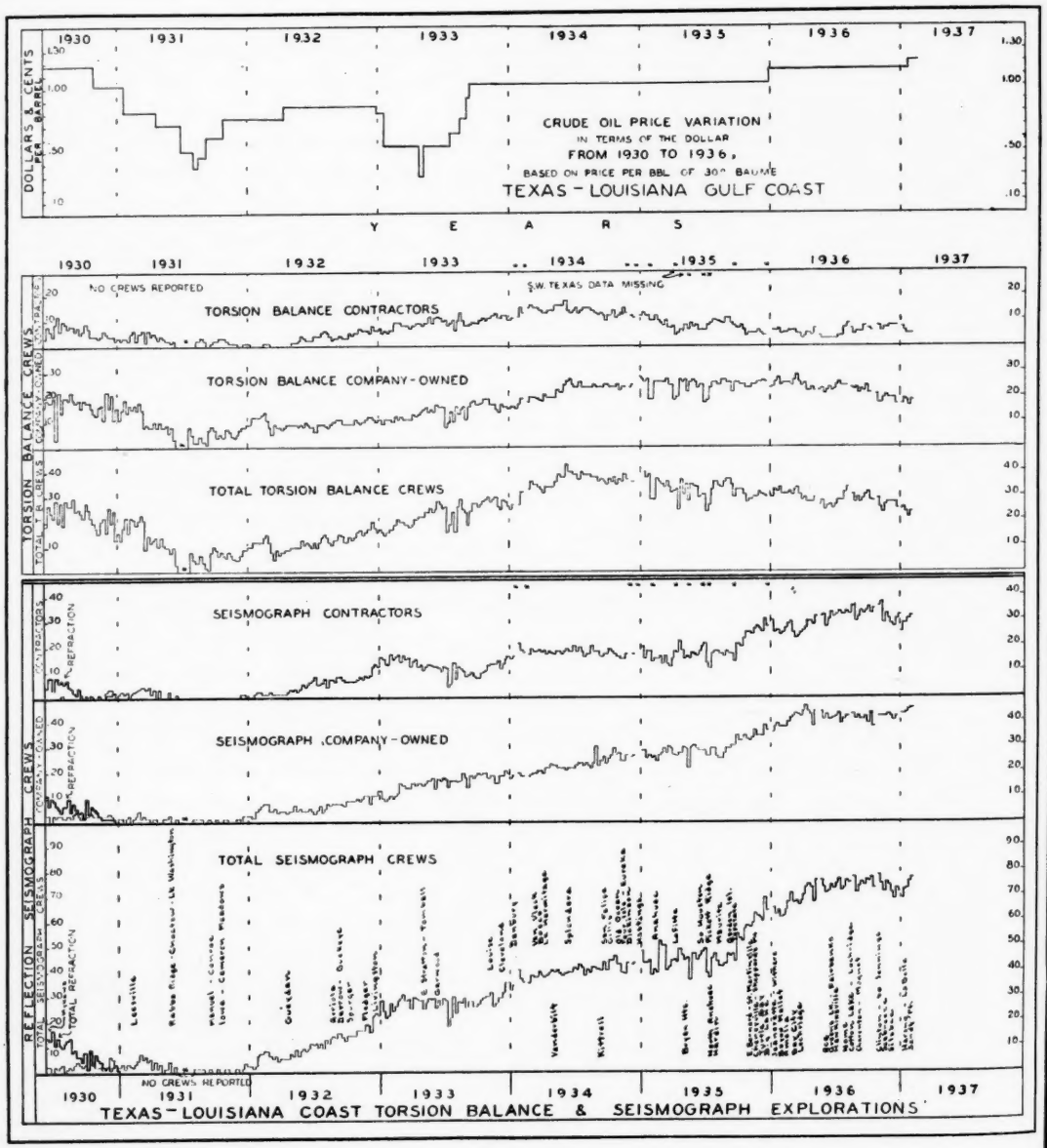

1930
1931
1932
1933
1934
1935
1936
1937
DOLLARS & CENTS PER BARREL
1.50
1.00
.50
.10
CRUDE OIL PRICE VARIATION
IN TERMS OF THE DOLLAR
FROM 1930 TO 1936,
BASED ON PRICE PER BBL. OF 30° BAUME
TEXAS - LOUISIANA GULF COAST
Y E A R S
TORSION BALANCE CREWS
NO CREWS REPORTED
S.W. TEXAS DATA MISSING
TORSION BALANCE CONTRACTORS
TORSION BALANCE COMPANY-OWNED
TOTAL TORSION BALANCE CREWS
REFLECTION SEISMOGRAPH CREWS
SEISMOGRAPH CONTRACTORS
SEISMOGRAPH COMPANY-OWNED
TOTAL SEISMOGRAPH CREWS
NO CREWS REPORTED
TEXAS - LOUISIANA COAST TORSION BALANCE & SEISMOGRAPH EXPLORATIONS

FIG. 2

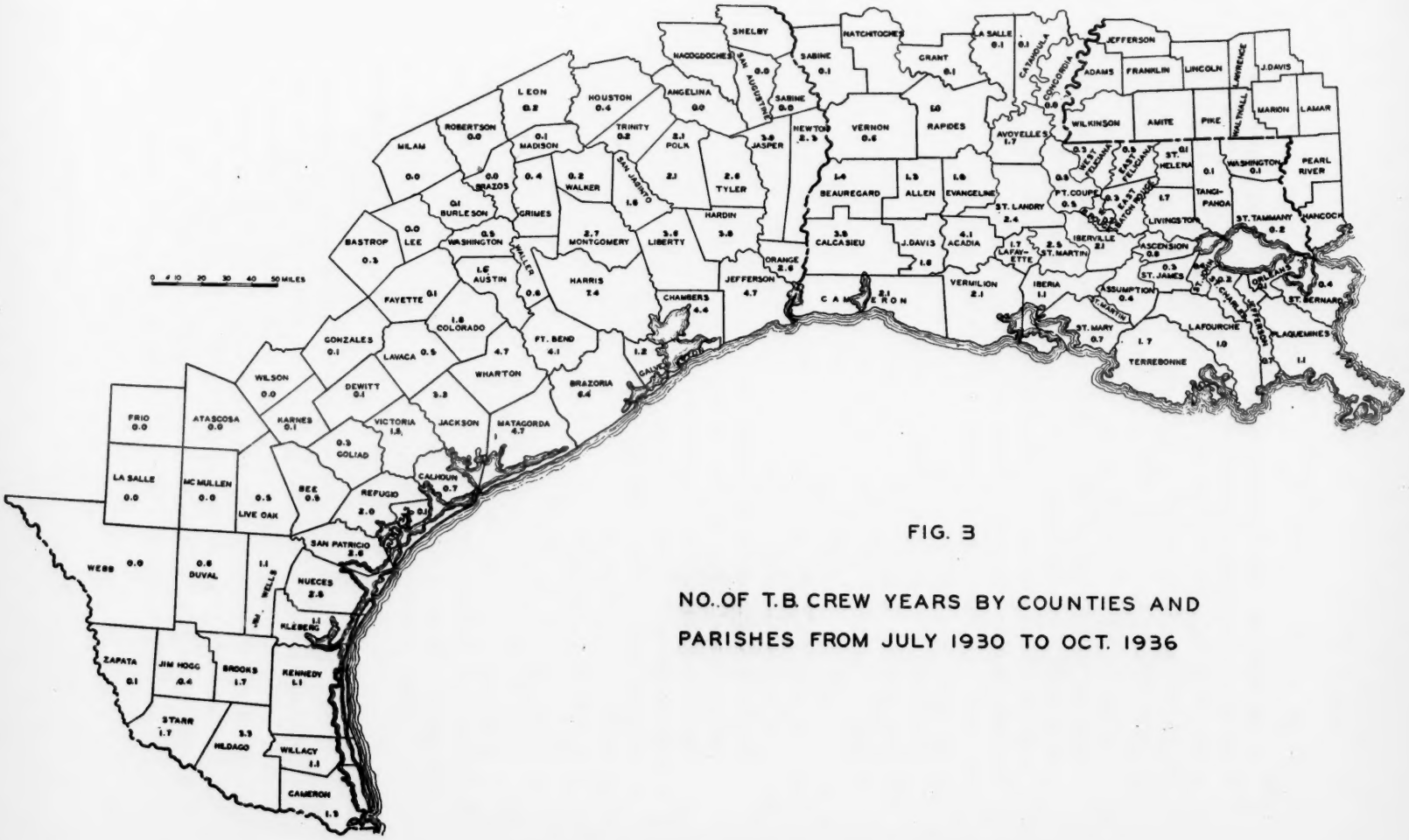


FIG. 3

NO. OF T.B. CREW YEARS BY COUNTIES AND PARISHES FROM JULY 1930 TO OCT. 1936

In Fig. 2 we reproduce a graph showing the total exploration for the two methods under consideration. Attention is called to the fact that while total torsion balance operations have reached their peak and are falling off, company-owned torsion balance operations are continuing at a nearly constant figure. On the other hand, seismic operations are still increasing, and company-owned operations are showing a steady increase not paralleled by the contract operations. It is quite probable that in the near future company-owned seismic operations will dominate that field as thoroughly as company-owned torsion balance crews now dominate the gravity exploration field.

The number of torsion balance crew years in each county or parish, since July 1930, is shown in Fig. 3. Similar figures for the seismic crew years in each county or parish are shown in Fig. 4. It is obvious that for both methods, Harris and Brazoria counties have received the greatest amount of attention. It is interesting to note that in the past six years, Brazoria County has been favored, practically, with one torsion balance crew and two seismic crews operating continuously.

To evaluate properly this attention, however, proper cognizance should be taken of the area considered. The total operations, for instance, show that Galveston County has received only one-fifth of the torsion balance attention, and one-third of the seismic attention that neighboring Brazoria County has. However, the areas, (Galveston 395 square miles, Brazoria 1340) are in the ratio of about one to three, so that Galveston County has not been neglected. So, if the geophysical exploration is assumed to have been uniformly distributed in each county and parish, the assumed uniform coverage can be calculated from the square miles given in Fig. 1, the crew years given in Fig. 3 and Fig. 4, and the assumed yearly performance for the average crew (500 square miles per year for the torsion balance crew and 1250 square miles per year for the seismic reflection crew).

These (assumed uniform) coverages are shown in Figs. 5 and 6 respectively, while in Figs. 7 and 8, respectively, they are presented graphically.

The seven Texas counties and the five Louisiana parishes most ex tensively explored are Orange, Chambers, Galveston, Brazoria, Harris, Jefferson, and Ft. Bend counties, and Calcasieu, Jeff Davis, Acadia, Lafayette, and St. Martin parishes. They comprise but 9.5 per cent of the total area under consideration, yet the accumulated activity in these counties and parishes involves almost one-third of all torsion balance exploration and nearly 40 per cent of the total seismic

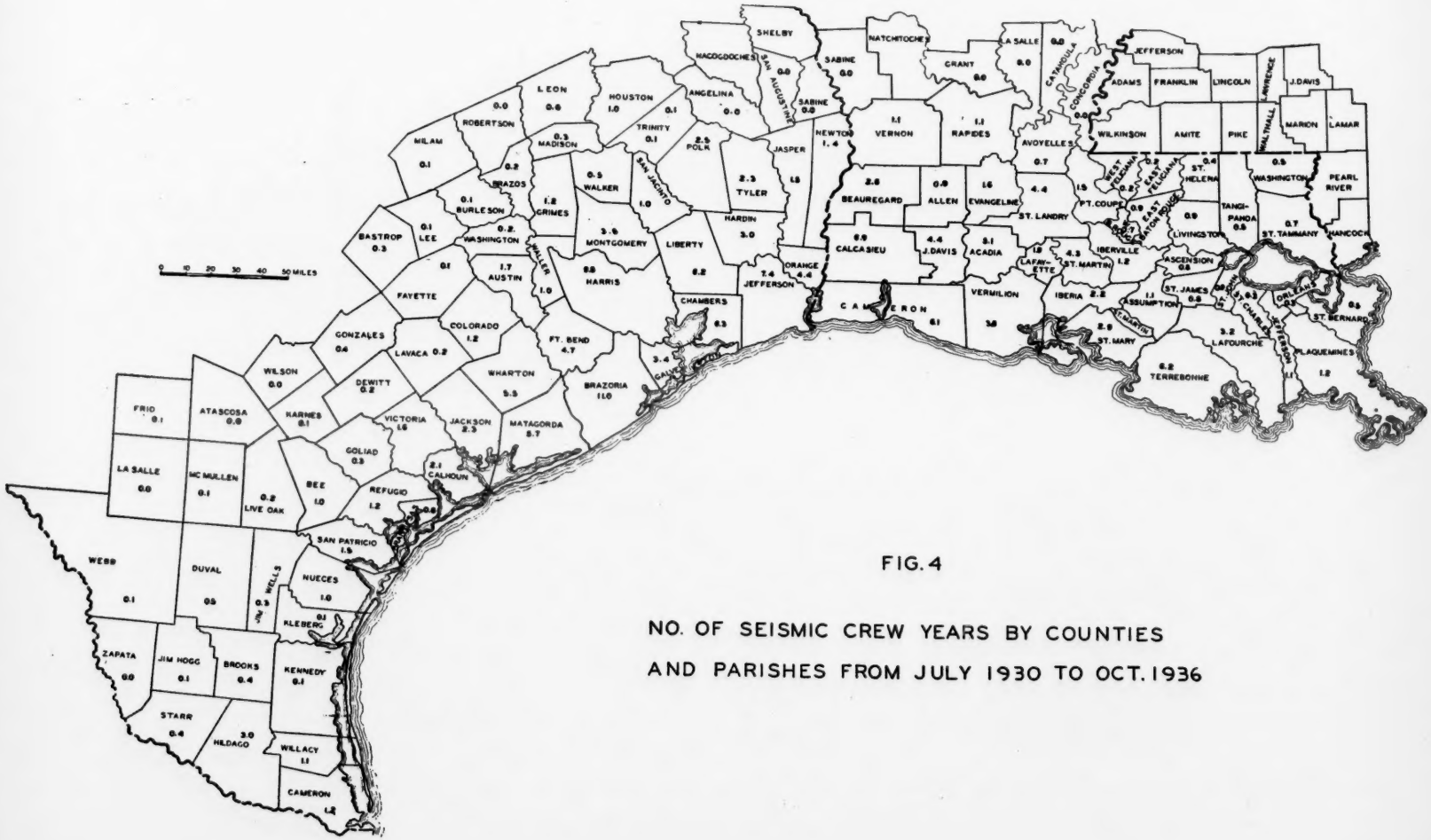


FIG. 4

NO. OF SEISMIC CREW YEARS BY COUNTIES AND PARISHES FROM JULY 1930 TO OCT. 1936

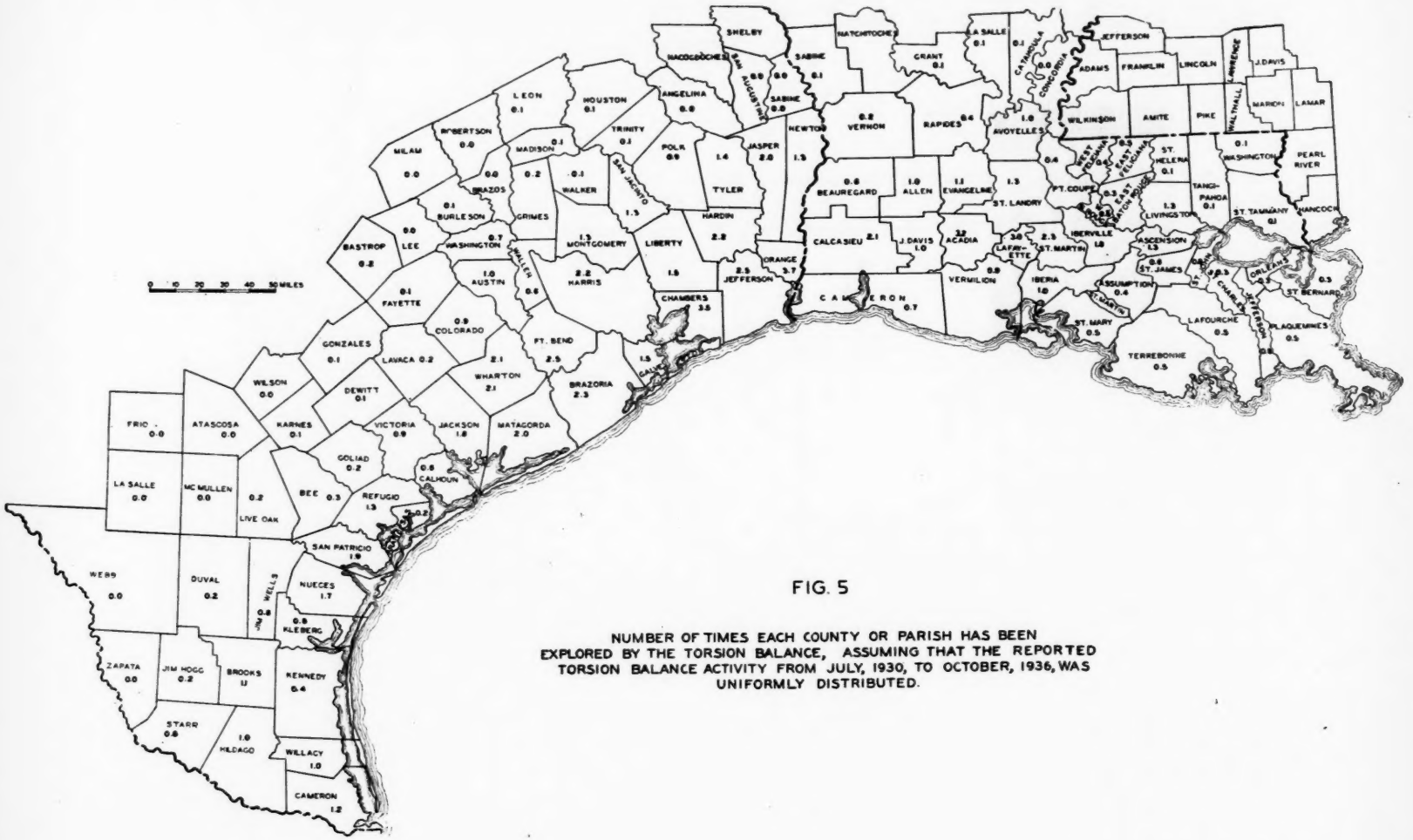


FIG. 5

NUMBER OF TIMES EACH COUNTY OR PARISH HAS BEEN EXPLORED BY THE TORSION BALANCE, ASSUMING THAT THE REPORTED TORSION BALANCE ACTIVITY FROM JULY, 1930, TO OCTOBER, 1936, WAS UNIFORMLY DISTRIBUTED.

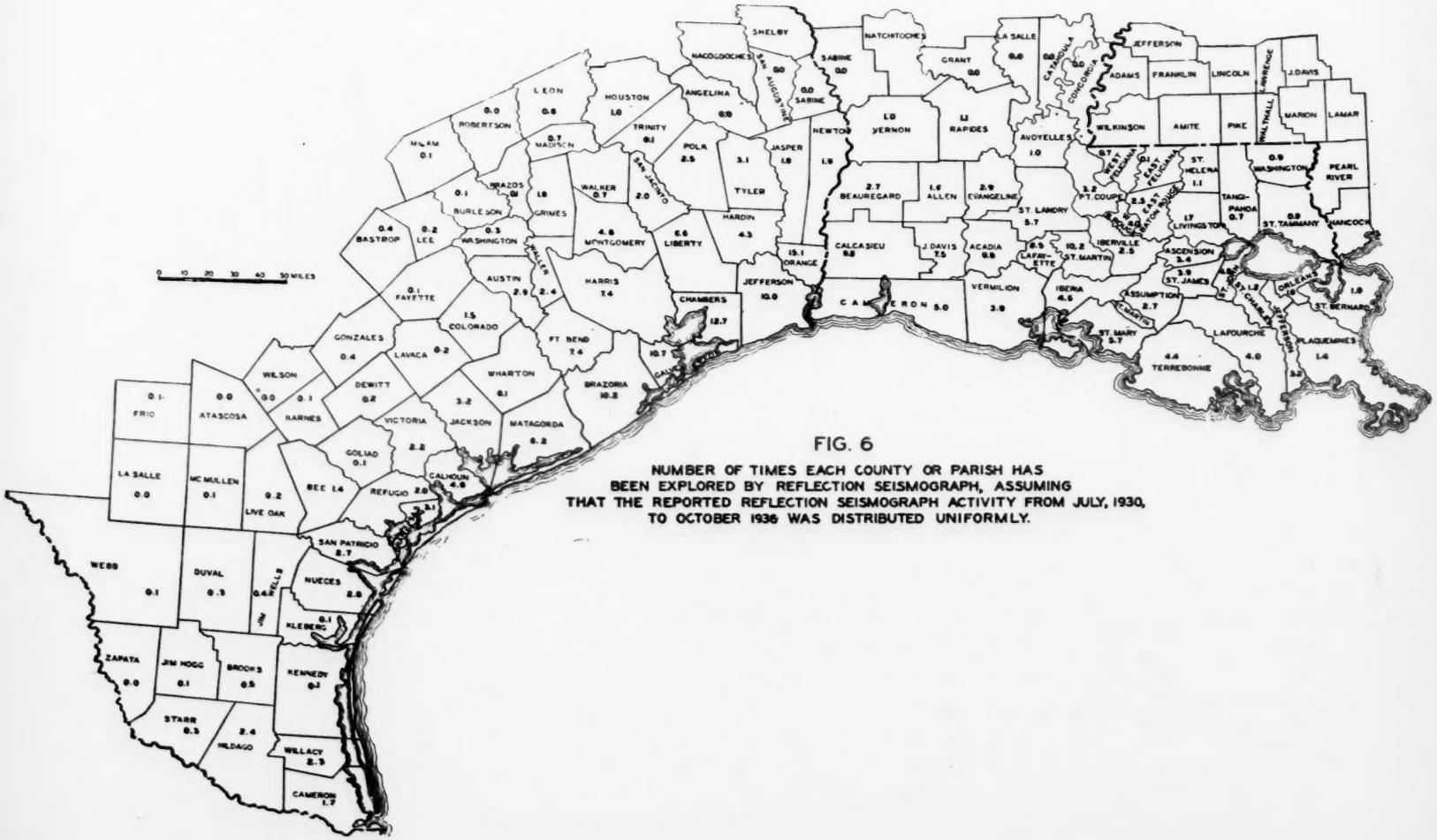


FIG. 6

NUMBER OF TIMES EACH COUNTY OR PARISH HAS BEEN EXPLORED BY REFLECTION SEISMOGRAPH, ASSUMING THAT THE REPORTED REFLECTION SEISMOGRAPH ACTIVITY FROM JULY, 1930, TO OCTOBER 1936 WAS DISTRIBUTED UNIFORMLY.

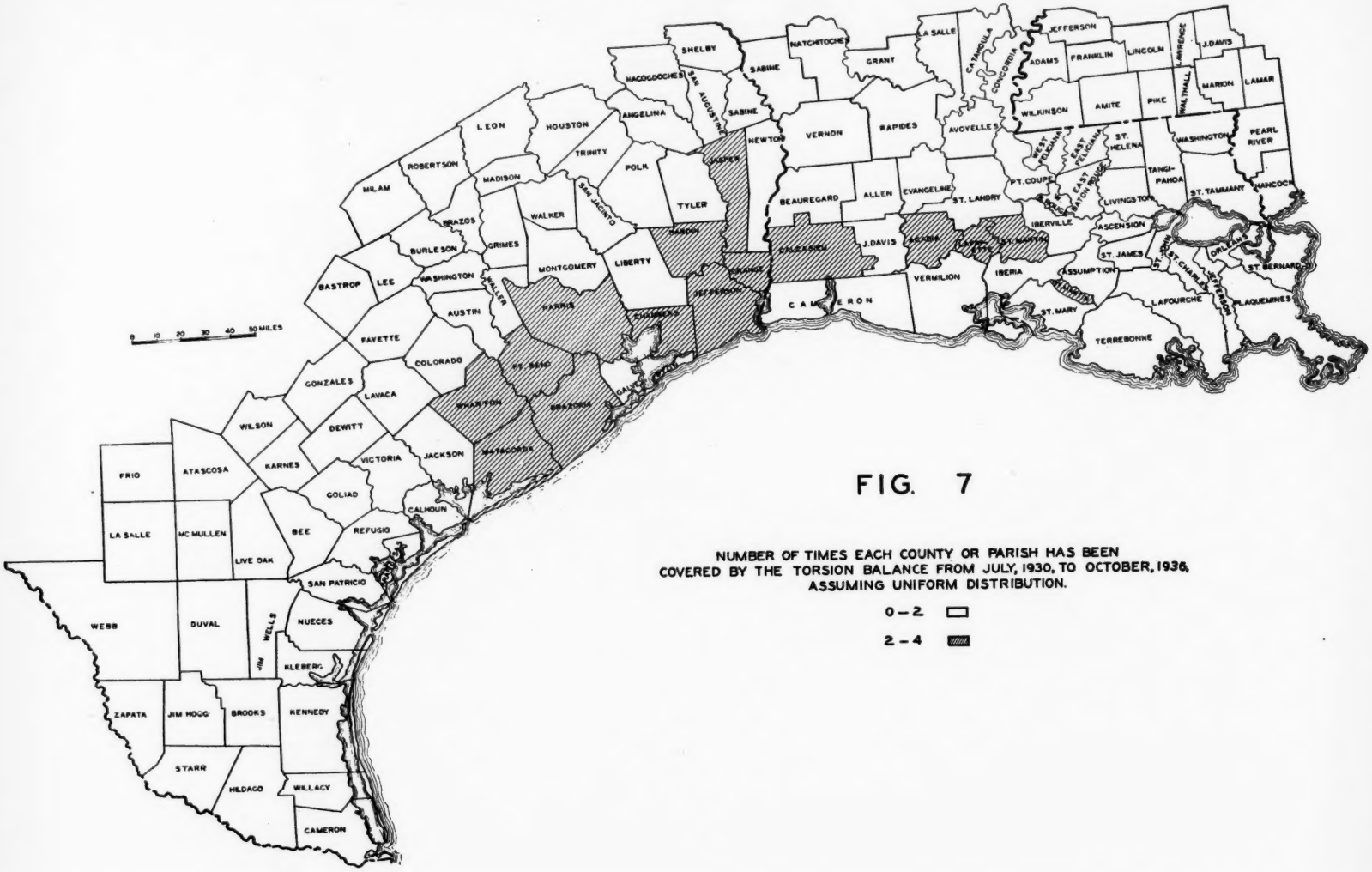


FIG. 7

NUMBER OF TIMES EACH COUNTY OR PARISH HAS BEEN COVERED BY THE TORSION BALANCE FROM JULY, 1930, TO OCTOBER, 1936, ASSUMING UNIFORM DISTRIBUTION.

0 – 2 ▭

2 – 4 ▨

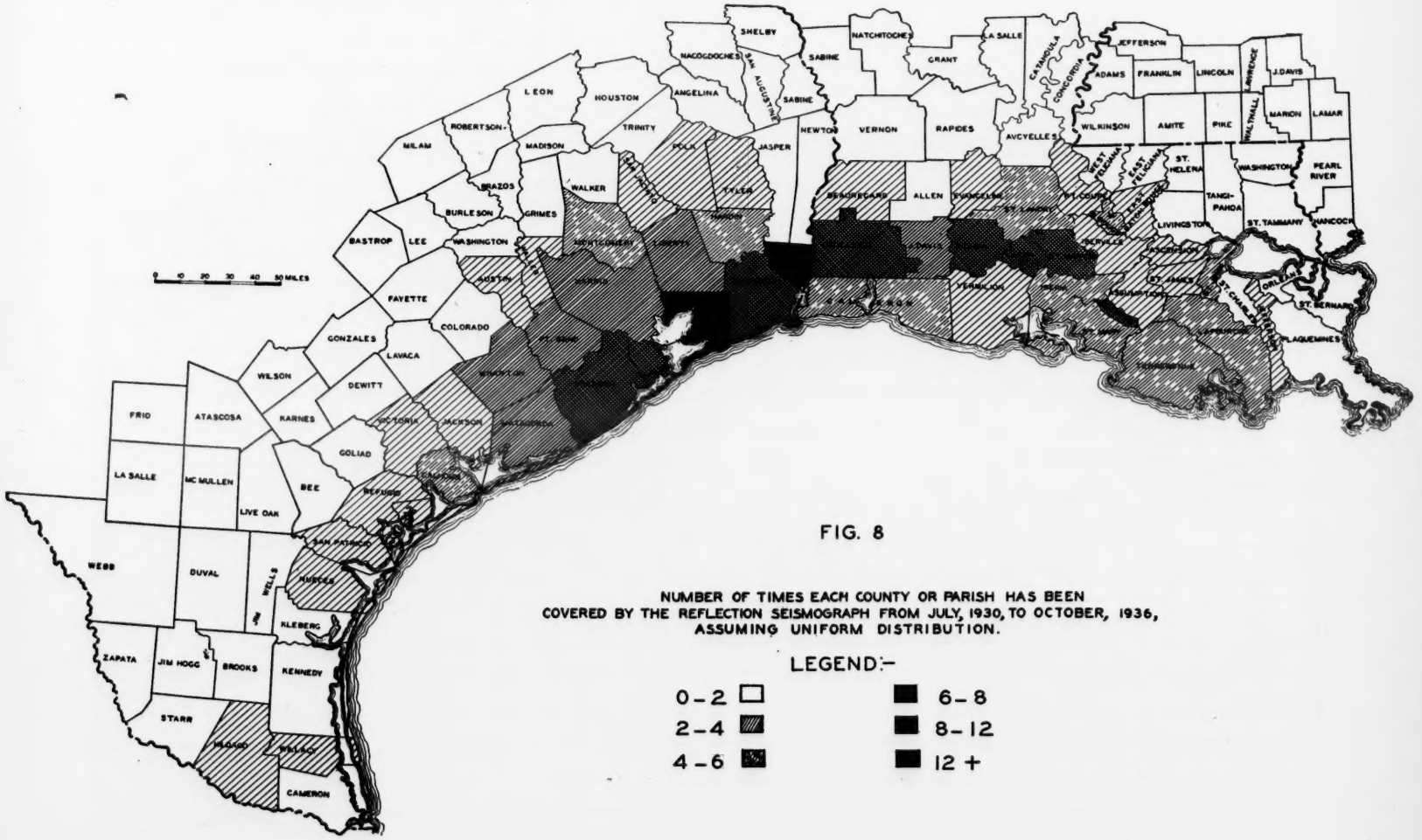


FIG. 8

NUMBER OF TIMES EACH COUNTY OR PARISH HAS BEEN COVERED BY THE REFLECTION SEISMOGRAPH FROM JULY, 1930, TO OCTOBER, 1936, ASSUMING UNIFORM DISTRIBUTION.

LEGEND:-

0-2	6-8
2-4	8-12
4-6	12 +

EXPLORATION RATES IN THE 12 COUNTIES AND PARISHES MOST INTENSIVELY WORKED.

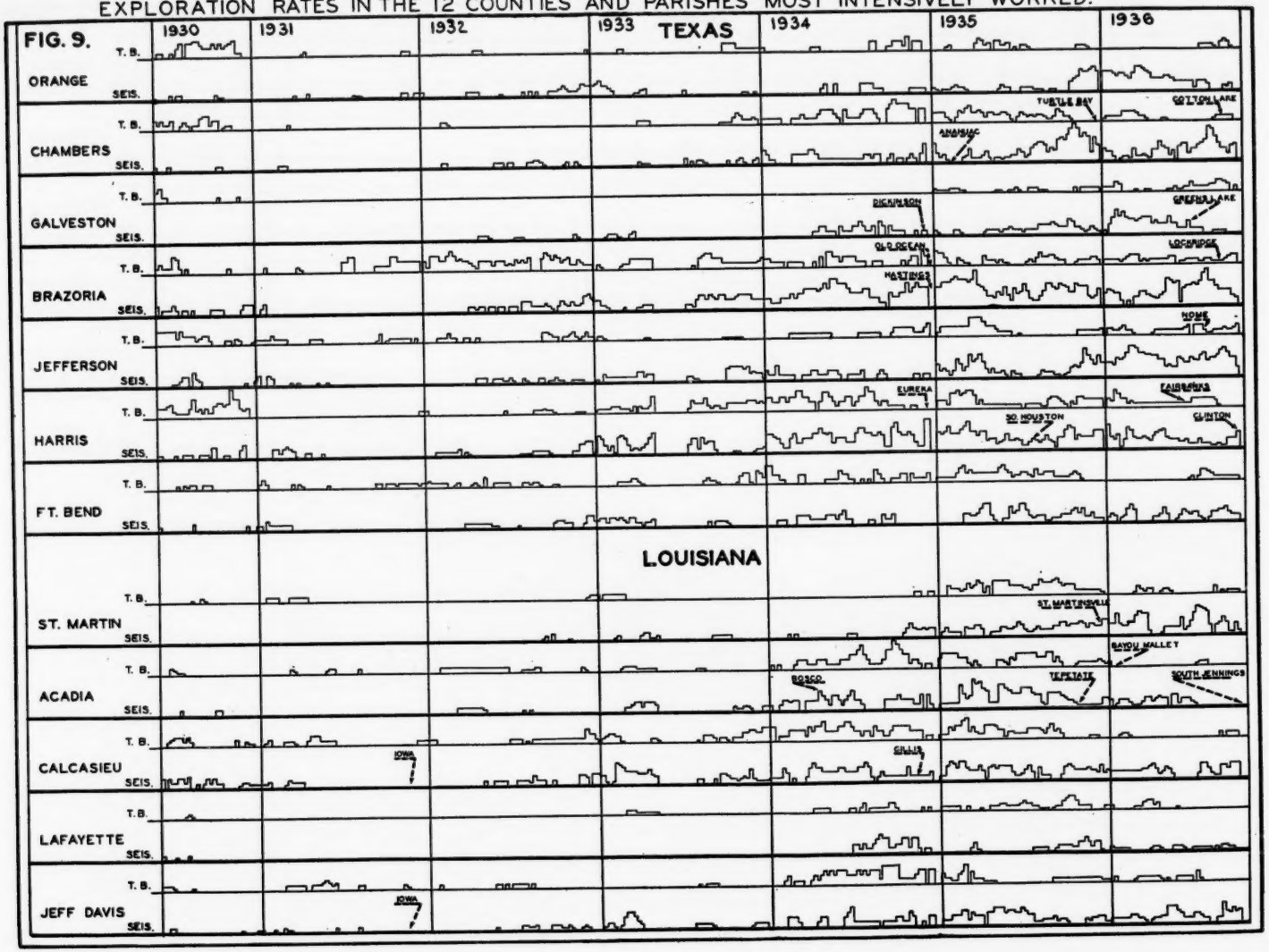


FIG. 9

exploration for the area since July 1930. Of the total expenditure of something over $22,000,000 for both forms of activity in the past six years, about 38 per cent, or about $8,500,000, have been spent in these twelve counties and parishes.

It is interesting to note that not quite 40 per cent of the Gulf Coast oil fields, in the discovery of which, since 1930, geophysics has played an important part, have also been found in these twelve counties and parishes. The apparent conclusion is that the reward has been proportional to the effort, so that, apparently, there was no discovery at a premium. However, in Fig. 9, we have plotted the weekly activities for these twelve counties, with the dates of oil field discoveries therein. Granting that at least six months time intervenes between discovery by geophysics and the discovery of oil, this last analysis shows that the rewards went to the early birds and that, with the possible exception of Cotton Lake, in Chambers County, Texas, the bulk of this extensive effort was its own, and only, reward.

The question then arises as to whether these rather conspicuous over-runs are accidental, psychological, or a logical consequence of exploration.

The spectacular success gained by the Stanolind at Hastings, South Huston, Turtle Bay and Clinton is an outstanding example of the success which followed the exploration sequence of prospect discovery by the torsion balance and prospect evaluation by the reflection seismograph. It is generally assumed that seven companies (Gulf, Shell, Humble, Sun, Texas, Stanolind and Magnolia) have operated the torsion balance on a "grand scale," (i.e., approximating coast-wide operations). Since the data which went to make up Fig. 5 go back only to July 1930, the torsion balance operations of the first three (Gulf, Shell, and Humble) are only partially included. Even so, the data of Fig. 5 are lower than would be expected, and suggest that one of the following hypotheses should be taken into account.

1. Mr. Pollard's estimate of 500 square miles per year for torsion balance crew is too low (as it may well be for the torsion balance work done prior to 1932).

2. No one of these seven companies has a complete gravity map of the Gulf Coast.

3. The extent to which torsion balance data has been supplemented by pendulum and gravity meter exploration is more than is generally assumed.

Now if hypotheses one and three are not justified, then prospect

FIG. 9

discovery by the torsion balance is still worthy of material consideration. The success of the Stanolind suggests that, in 1932, the second hypothesis was far from being unreasonable.

Each of the seven companies who have operated the torsion balance on a grand scale are also, apparently, utilizing the reflection seismograph to the same extent. In addition, the Tide Water, Amerada, Pure, and California Company are operating this latter method on at least a "semi-grand" scale. Thus, if complete figures were finally made available, it would not be unreasonable to expect that gravity coverages of seven and seismic coverages of ten would be not infrequent.

It is apparent now that these latter four companies have been operating at a distinct advantage in that they did not make general use of the torsion balance for prospect discovery. However, with the transition to the stage of prospect discovery by the seismograph, the advantage accruing from gravity prospecting will be minimized. At the end of this stage of prospect discovery by the reflection seismograph, the relative advantages and disadvantages, between these companies, will be determined by their relative coverage with this method and their investment in marginal prospects. Further, upon the introduction of a new method of still higher finding power, their relative positions will be proportional to their individual knowledge of the marginal and submarginal prospects discovered by the reflection seismograph.

From the standpoint of the present, when primary reliance is placed upon the reflection seismograph, three general areas in the Gulf Coast should be recognized, as shown in Fig. 10.

Reflection seismograph technique has been developing year by year and in each succeeding year the problems have been harder. For a parallel situation, we suggest the position of the refraction seismograph in 1927, and the use of that method in the most spectacular exploration campaign ever staged in this province, the show put on by the G. R. C. for the account of the Louisiana Land & Exploration Company in 1927–8, when nine salt domes were found in eleven months. That record was discovery at a premium and represented, essentially, the use of a highly developed exploration technique, (the refraction seismograph) in an area as yet unexplored; the case of an old method in a new area. With the repeated indications that the Wilcox does carry some oil, as witness Clay Creek and Urania, a similar opportunity, to utilize a well-established method in an untested area, again appears on the scene.

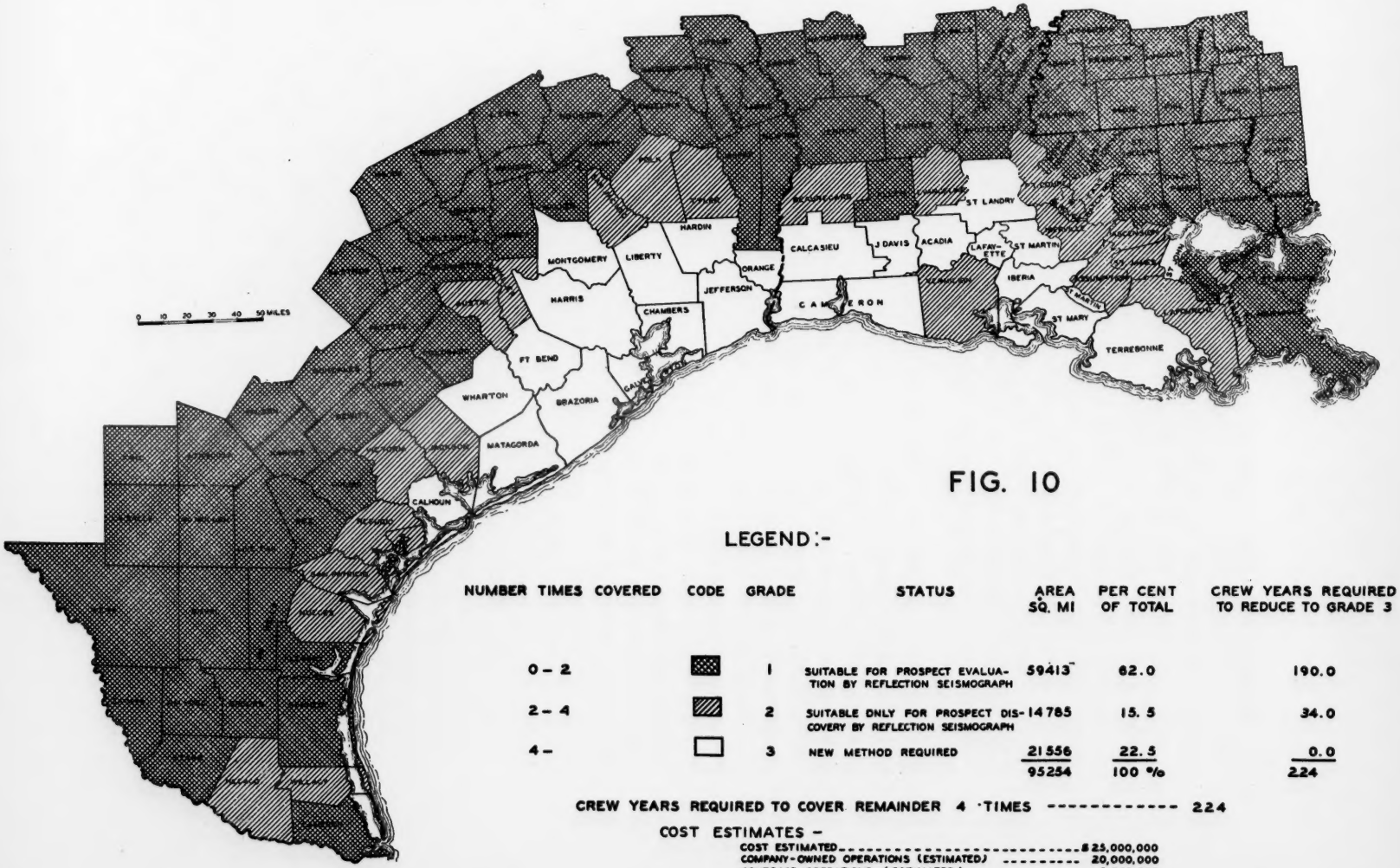


FIG. 10

LEGEND:-

NUMBER TIMES COVERED	CODE	GRADE	STATUS	AREA SQ. MI	PER CENT OF TOTAL	CREW YEARS REQUIRED TO REDUCE TO GRADE 3
0 – 2		1	SUITABLE FOR PROSPECT EVALUATION BY REFLECTION SEISMOGRAPH	59413	62.0	190.0
2 – 4		2	SUITABLE ONLY FOR PROSPECT DISCOVERY BY REFLECTION SEISMOGRAPH	14785	15.5	34.0
4 –		3	NEW METHOD REQUIRED	21556	22.5	0.0
				95254	100 %	224

CREW YEARS REQUIRED TO COVER REMAINDER 4 TIMES ---------- 224

COST ESTIMATES –

COST ESTIMATED	$25,000,000
COMPANY-OWNED OPERATIONS (ESTIMATED)	20,000,000
CONTRACT OPERATIONS (ESTIMATED)	5,000,000

While it is difficult to conceive of any method which could better the performance of the reflection seismograph in predicting the results of the drill, still the method has at least two limitations of material importance. One is with regard to the location of stratigraphic traps, and the second in the recognition and location of faulting in those areas where acoustic correlation is difficult, unreliable, or even impossible. Should methods be developed which would accomplish either or both of these two ends,—and experiments now in progress offer material hope of accomplishing such achievements,—these new methods would prove of inestimable value in the evaluation of existing marginal and submarginal prospects discovered by the reflection seismograph.

The operating figures quoted above indicate that reconnaissance by the reflection seismograph cannot be done for less than ten cents an acre. It is quite possible that effective reconnaissance could be done by some of these new methods now in trial for less than five cents an acre. However, even though these new methods might well have finding powers greater than that of the reflection seismograph for particular problems, it is improbable that the reflection seismograph would be rendered obsolete.

For instance, assume that, overnight, cosmic rays were found to be localized above deposits of oil and gas. In a very short while, all district geologists would be asked to pass judgment on cosmic ray anomalies. Some of these, of course, would be near dry holes, and some others might, accidentally or otherwise, coincide with torsion balance anomalies, seismic highs, or even recognized but dry structures. But, on the other hand, some would be sure to fall out in the bald prairies, far from any known subsurface conditions. It is evident that, in such cases at least, the natural solution would be to detail the anomaly with the reflection seismograph, and, in addition, secure tie-ins to the nearest points of control. Those companies who have contributed materially to conspicuous over-runs of exploration are simply doing that in advance, and besides, they have thereby developed prospects for immediate evaluation upon the introduction of a new method of higher finding power. They are building up libraries of geophysical data.

A RESEARCH LIBRARY IN THE GEOPHYSICAL FIELD*

JAMES B. MACELWANE, S.J.

ABSTRACT

The author points out the problem arising from the rapid accumulation of geophysical data in large amounts in the various companies. Much of this material is obsolete or is such that making it available to the research worker would entail no loss to the owners. The author suggests that a library, suitably staffed with competent scientists, might be set up, in a centrally-located institution, where the material might be made available to the proper workers. This library might also be equipped with vaults for such data as the owners wish to be kept confidential for an indefinite period of time, and in that way, function also as a depository as well as a working library.

The organization and steady growth of the Society of Exploration Geophysicists (formerly the Society of Petroleum Geophysicists), the excellent programs of scientific papers, the extended and frank discussions that have characterized its recent meetings, and especially the publication of a journal with as high a scientific standard as GEOPHYSICS, to me mark the auspicious dawn of a new day in the field of geophysical exploration. Happily passing away with the shadows is that hair-raising nightmare of exaggerated secretiveness and ogreish suspicion which sprang from the desire to hide from other eyes the scientific unpreparedness of the explorer and the inability of the executive to penetrate the darkness in order to disciminate intelligently between scientific facts of general interest and particular information that was of commercial value.

The more enlightened outlook seems to have come from the gradual diffusion among all those concerned with geophysical prospecting of so large a body of general knowledge concerning geophysics as, on the one hand, to make it obviously ridiculous to try to hide what everyone knows, and on the other hand, to expose quickly and mercilessly not only the fraud and the charlatan but also the would-be geophysicist who is sincere but untrained.

Everyone knows how anxiously each company which is engaged in geophysical prospecting searches for every scrap of information it can obtain concerning a given area before it undertakes its exploration by geophysical means. Those responsible are well aware how costly are the methods by which this knowledge is now secured and how inadequate these methods often prove to be. Usually there is far more

* Paper presented at the meeting of the Society of Exploration Geophysicists at Houston, Texas, November 20, 1936.

known beforehand than the investigators are able to find. The difficulty does not lie in the reasonable secrecy with which the information ought to be guarded; for, once the interested oil company has secured its block of land by lease or purchase, the actual commercial value of the geological and geophysical information concerning the prospect has practically ceased. But one commercial concern will hesitate to give documentary information directly to a competitor even though the knowledge has no further money value to the holder.

In the course of the last ten years there has accumulated in the files of American and foreign petroleum corporations and of geophysical prospecting companies a large mass of records and data that are commercially obsolete. This material will become more and more of a burden and one can foresee the day when pressure for needed space or the exigencies of moving or of reorganization will cause it to be destroyed or disposed of otherwise. In fact some of it has already been lost. Yet the original records are simply irreplaceable. Once lost they are gone forever. Will not the same happen in future years to the records that are being made with so much labor and expense at the present time?

Is there no feasible means of averting such an irreparable loss to geophysical science? Is a research library the answer? The writer feels that if the means can be found to gather these materials together into such a library this will not only provide a satisfactory solution for the future but will also supply a present need whose magnitude is only partially realized by geophysicists and executives. What is a research library?

A research library to be worthy of the name should fulfill three requirements. In the first place it should be a *depository* of geophysical information and documents. It should be a suitable building where seismic and other geophysical records that are no longer of immediate use to the organizations that secured them can be deposited with the assurance that they will be preserved and properly cared for and will be at the disposal of the depositors for further use whenever the need should arise. Geophysical information in general falls into four classes. There are first the original data sheets, seismic records, reports, maps, and the like which concern active areas not yet developed. Obviously this class of information is, at least potentially, of commercial value and will be guarded with the utmost secrecy in the files of the interested parties. In the second place there are similar documents which relate to fully developed areas. These documents might be deposited

in a research library subject to any restrictions the depositor saw fit to impose, such as filing under lock and key or placing in a safety deposit vault in the library. Thirdly, there is a large mass of information stored away in the files of the petroleum corporations and of the prospecting companies which is obsolete or concerns structures that have been proven barren. This class of information has no present commercial value, is referred to but rarely and yet is occupying valuable space. It would be greatly in the interest of the companies concerned if it were deposited in a library under competent care. The fourth class of information is non-commercial. It consists partly of unpublished geological and geophysical studies, manuscript maps, models, well logs, statistics and the like which have been made or gathered by the national and state surveys and by individuals, and partly also of books, journals, monographs and all other publications of geological and geophysical character. Now a research library should be a repository where all available materials of the third and fourth classes would be found and where at least some of the second class would be deposited.

The second requirement of a geophysical research library is that it be a ***working library***. It must, therefore, be well organized and served by a competent staff so that the precious documents it contains may be made available to the extent desired by the depositors, and so that all the published and unpublished information of the fourth class may be fully available to any competent investigator consulting the library. It is conceivable that a concern which would otherwise be loath to part with the information of the second class in its files would be led to deposit it in the research library for the sake of the sheer convenience of having simultaneous access there to all the other available information relating to the same areas, thus making correlation possible under the most favorable working conditions.

The third and final requirement of a geophysical research library is that it be a part of a ***research institution***. The materials that will be deposited in such a library will be exceedingly heterogeneous both in subject matter and in relative value. The records that are deposited in the library will have been made with widely different instruments and methods. The accompanying information will be more or less complete—frequently less—and the lacunae will have to be discovered and supplied before the sources of information disappear. It is perfectly obvious that no ordinary library staff could do this; nor could anyone but a geophysicist catalogue and correlate all these technical materials

in so satisfactory a manner that a patron of the library asking for all the existing information on a certain area, could have the documents brought to his working table in immediately usable form. Not only would the librarian have to be a trained and scholarly geophysicist himself but he would require ready access at all times to a corps of highly trained colleagues actively engaged in research in the various fields of geophysics. For the librarian would have the unique responsibility of devising an entirely new system of classification and cross reference for such a collection in order to make all the materials completely accessible to himself and his staff on a moment's notice, and, in addition, he should be capable of rendering intelligent assistance to patrons in their problems. Furthermore, it is only with the help of a group actually engaged in research in both pure and applied geophysics that any librarian could be expected to discover what information is lacking in the collections and where and how it can be best secured. Clearly it is only a geophysical institute in a University setting that could furnish either such a librarian or the research atmosphere for such a library.

In conclusion let me sum up briefly the reasons for such an institution as I have proposed. The creation of a geophysical research library of the type described will, in the first place, preserve from ultimate destruction original records and data of inestimable scientific value that, once lost, will never be replaced because of the cost. Secondly, such a library will provide the opportunity to geophysical prospecting units of securing in one place and under the most favorable conditions all the public information available on an area before going into it. Thirdly, the library will itself add greatly to geophysical knowledge, for the correlation and evaluation of records and documents will bring out new facts and scientific relationships. Fourthly, the presence of the library and the challenge of its problems in a university atmosphere with a background of pure science will greatly stimulate the broader research activities of the whole geophysical institute of which the library should form a part. Lastly, to secure the best results, the location should be central with reference to the whole country, and the staff must be above all suspicion of favoritism toward any particular interest or commercial concern.

GRAVITATIONAL SURVEYING WITH THE GRAVITY-METER

L. M. MOTT-SMITH

ABSTRACT

The paper discusses briefly the history of gravity meters and the importance of gravity surveys for the prospector. The relative advantages claimed for the gravity meter over the torsion balance and pendulum, from the points of view of adaptability to field work, corrections and accuracy, are brought out. The paper also discusses the methods of observation, particularly in regard to "drift."

The subject of this paper is how to obtain what is popularly known as a "Gravity Picture." Putting it a bit more scientifically, by this is meant making a survey the object of which is to obtain a series of lines on a map along each of which the force of gravity has a given constant value, or, in other words, obtaining a series of gravity contours.

Much effort and money have been spent during the past ten years in obtaining these gravity maps, because it is often possible to find indications of economically interesting geologic structures by looking for the proper convolutions in the contours of the maps.

Though statistics are not at hand, a guess may be ventured that about ninety-eight per cent of the gravity maps obtained to date have been made with the torsion-balance. The torsion-balance has undoubtedly done good work, and many of the surveys made with it must be reasonably accurate representations of the true changes in the force of gravity over the area. It has, however, certain inherent weaknesses, which improvements in instruments and operating technique can hardly be expected to overcome. The most serious fault is the necessity of deducing the change in gravity from one point to another from the rates of change of gravity, which the instrument measures. This makes the torsion-balance excessively sensitive to nearby terrain irregularities, which may cause a large gravity gradient over a small area without appreciable effect on the actual value of gravity. As a result the accuracy of the work is considerably affected when operating over irregular terrain. In fact, in many regions torsion-balance work is of highly doubtful value on this account. Some quantitative data on this point will be presented below. A second disadvantage is that of the time required to take a reading. This interval of time is principally determined by the period of oscillation of the

suspended system, and, though great efforts have been made to reduce this to as small a figure as possible, it necessarily limits the number of stations which can be obtained with a single balance to about six per day.

Thoughts such as these have led numerous people to attempt to improve upon the torsion-balance. Efforts have been particularly directed toward avoiding the necessity of deducing changes in gravity from the gradients by developing some means of obtaining the gravity differences directly. One well known possibility is the pendulum. Considerable work has been done in developing pendulum apparatus so as to have sufficient accuracy and speed to compete with the torsion-balance. Judging from recent reports the accuracy of some of the latest pendulum outfits compares favorably with the torsion-balance work, especially when considering large scale maps. The apparatus, however, seems at present too cumbersome and slow to compete seriously with other methods though it may be valuable in some cases for large scale control, as many geophysicists have pointed out, because the accuracy in determining gravity differences by the pendulum does not depend on the distance between stations, as is the case with the torsion-balance.

Another approach to the problem is that which is the particular subject of this paper, namely the so-called gravity-meter, gravity-balance, or gravimeter. This instrument is in principle the simplest of all methods of measuring gravity, a fact which perhaps accounts for the stupendous amount of work which has been done on its development during the past one hundred years. The first suggestion of the possibility of using a simple spring balance, or a mass supported by a spring, to measure changes in gravity was made by the famous English astronomer and physicist, Sir John Hershel in his book "Outlines of Astronomy" first published in 1833. Fig. 1, taken from Hershel's book, shows his design. To operate, the top of the spring was adjusted until the weight just touched the base plate. The spring and weight were then to be carefully unhooked and stored in a box while the instrument was being carried to the next station. Here it was to be again set up, and small weights added or removed to again cause the main weight to just touch the base. The change in weight served as a measure of the change in the force of gravity.

In principle this gravity-meter would work, but its accuracy would have been far poorer than even the pendulums of those days because Hershel forgot that changes in length of his spring far greater than

those caused by changes in gravity would be produced by changes in temperature, and by the disturbances caused by mounting and dismounting. There are of course several other reasons why the modern gravity-meter only remotely resembles Hershel's. To indicate the progress which has been made since Hershel's day a recent model of a gravity-meter is shown in Fig. 2.

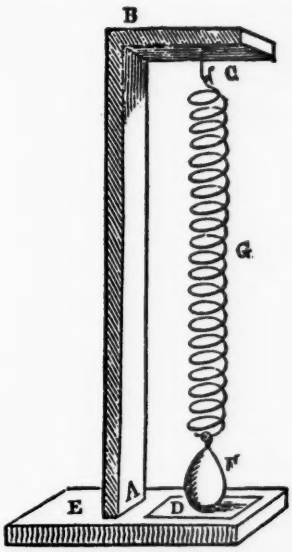


FIG. 1. Hershel's gravity meter.

After Hershel came a long series of papers describing various other types of meters, climaxing in sufficient interest among physicists of the eighties to cause the Royal Society to offer a prize to anyone constructing a gravity-meter which would come up to certain specifications which they set up. No less a figure than Lord Kelvin entered a model.

In this early work the effort was directed toward building a light portable machine which could measure the force of gravity to about one part in 100,000 so as to compete with the pendulum apparatus which was then being used for making world-wide large scale graviattional surveys. One or two meters satisfying these requirements were actually built between 1895 and 1910 but they proved to be less reliable than the pendulum and were not extensively used.

After the development of the torsion-balance, which could determine the difference in the value of gravity between two stations say a mile apart with an accuracy of about two to three parts in ten million, it became evident that to compete with it for the purpose of making detailed surveys the accuracy of the gravity-meter would have to be stepped up by a factor of about one hundred. Many experimenters have worked toward this goal, the interest undergoing a considerable rise around 1920 when it became evident that gravity maps were economically valuable.

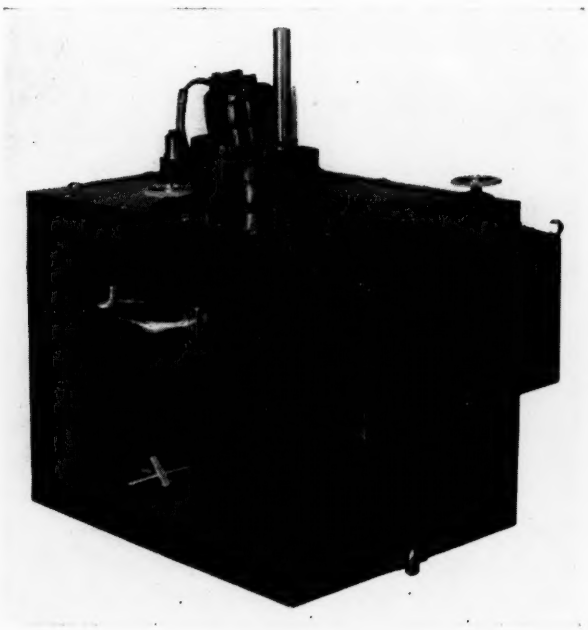


FIG. 2. Modern gravity meter.

Despite these efforts, there are today apparently only three or four designs of gravity-meters which attain the necessary accuracy of one part in ten million.

It may be of interest to outline how gravity pictures are obtained with the meter and to show some of the results exhibiting the accuracy which can be attained, and also how the meter compares with its competitor the torsion-balance.

In principle our meter is a mass on a spring just like Sir John's,

except that we have no helical spring and practically no mass. Also we do not take our outfit apart when we move from one station to the next. In fact we go to considerable pains to disturb it as little as possible. However, the vertical movement of the mass caused by changes in the force of gravity is determined and serves as a measure of these changes. Thus to measure differences in gravity between say stations A and B the meter is first set up at A and the position of the mass read, then taken to B and the position again observed. From the difference in scale readings and a calibration curve the desired gravity difference is obtained. As a check to make sure that everything is working properly the instrument is occasionally returned to A to see if the same reading is obtained. With a perfect meter exactly the same reading should of course be obtained. However, our meter, and apparently all others, is not quite perfect, and it is found that the mass very slightly but appreciably moves down slowly at a more or less constant rate, so that on returning to A a few hours later the reading is somewhat different. This effect is called "drift" and is caused by the fact that even the best elastic materials are not quite perfectly elastic but slowly and continuously yield under stress. If this drift is constant, that is if the weight moves down at a constant rate its motion can easily be allowed for and does not reduce the accuracy of the instrument. During a typical day's work readings are taken at about twenty field stations and the meter is returned to the initial base station two or three times. The apparent values of gravity are then plotted against time, forming what is called a drift curve. Fig. 3 shows a typical drift curve. It will be noted that the apparent values of gravity for station No. 1, the bases, lie nearly on a straight line. The operator also repeated station 5 as an added check, and these points lie on a parallel line, as they should, within the limits of error of reading, which as will be shown later is about one part in ten million. Note that 21 new stations were determined in somewhat less than one full working day. The desired gravity differences are the differences between ordinates of the field points and those of the drift line at the same abscissa. To obtain a gravity map, many gravity differences are measured in this way between numerous field stations located one-half to one mile apart and one or more so-called base stations. If more than one base is used, it is of course necessary also to determine carefully the gravity difference between the bases. Having these data we assign an arbitrary value of gravity to the main base and compute the relative values of gravity at all the field stations. Next it is necessary

to apply certain corrections. In country which is not very hilly it is only necessary to apply two simple corrections, one for differences in latitude and one for differences in the elevation of the stations. The latitude correction serves to cancel out of the picture the change of gravity due to the figure and rotation of the earth; and the second eliminates the change in gravity due to changes in elevation. Having made these corrections, we can place the corrected gravity values on the map and draw in contours in the usual way.

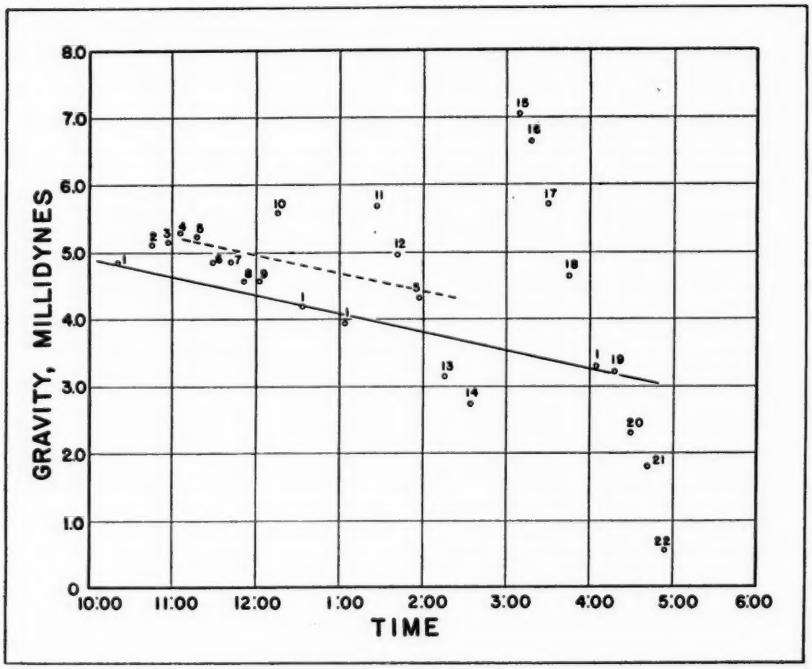


FIG. 3. A typical drift curve.

The value of such a map is of course largely determined by whether its accuracy is sufficiently definite to locate the structures being looked for. As geophysics progresses the demands made on the instruments are constantly becoming more severe. In fact it would be foolhardy to attempt to predict how high an accuracy may ultimately be found useful. It is evident, however, that a gravity-meter capable of obtaining as high accuracy as the torsion-balance would be highly desirable, because it would have two important advantages: that of greater

speed and that of being very much less affected by local masses or terrain irregularities, making it possible to get useful results in less favorable areas.

A meter has been developed which considerably exceeds the torsion-balance in accuracy, particularly on surveys covering many square miles in area. To exhibit the accuracy of the instruments, two types of data have been chosen. The first deals with a very simple and clear-cut accuracy test of the instrument. In the test, the same station was repeated ten times in succession. Between readings the in-

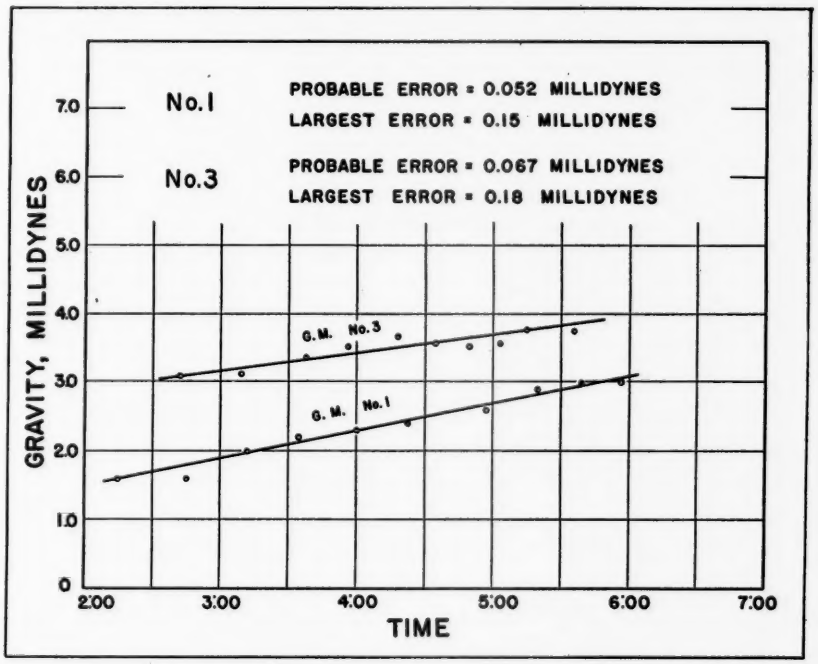


FIG. 4. Plot of repeated observations at the same station.

strument was picked up and transported in its truck a distance of about a mile for the purpose of simulating field conditions. This procedure is necessary, of course, because it is relatively easy to build a meter which gives reproducible readings if allowed to remain undisturbed. These data are given in Fig. 4. This test was made on our first instrument and also on our third. In each case the ten observed gravity values have been plotted against the time to form the usual drift curve. It will be noted that the points lie very nearly on a straight

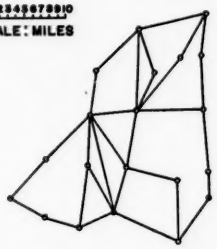
line, indicating a constant rate of drift. It also appears that most of the points deviate from the line by less than one-tenth of a millidyne, that is, by less than approximately one ten-millionth of the whole force of gravity. In fact the largest deviation for No. 3 instrument was 0.18 millidyne, while for No. 1 it was only 0.15 millidyne. The probable error of an individual reading has been computed in the usual way, by taking .67 of the root-mean-square deviation from the line. It turns out to be 0.05 millidyne for No. 1 and 0.07 millidyne for No. 3. The fact that our later instrument appears slightly less accurate than our first is probably accidental. Thus, as far as these tests go, it appears that the machine is able to give results which are reproducible to somewhat better than one part in ten million, which is the accuracy necessary to compete with the torsion-balance.

Another method of testing a gravity-meter, and one which is more exacting than the one just presented is to survey a network of stations and to test whether the measured changes of gravity around closed loops add up to zero. This is the familiar method of closures used in torsion-balance work, in levelling, etc. Such a test was made on our second instrument in collaboration with the geophysics department of the Continental Oil Company, and we are indebted to Dr. L. F. Athy of that Company for permission to use the results of this test. These results presented in Fig. 5. At the left is a scale drawing of the network of stations, each line representing a measured gravity difference. In this network there are eight loops involving five or less differences. The error of closure in each case is shown in the last column of the table. The first column gives the total gravity change around the loop, that is, the sum of the differences added without regard to sign; the second column gives the number of observed differences which were added together to form the loop. These data are presented since they may be of some interest. The largest error of closure was 0.26 millidyne, the average error 0.13 millidyne and the probable error 0.11 millidyne. The fact that this probable error is somewhat larger than that found in the previous test is to be expected since we are here dealing with the sum of several differences.

We have attempted to compare these results with those which would have been obtained by a torsion-balance working over the same area. To do this we have used data on torsion-balance accuracy given by Dr. Barton in his 1932 article entitled "Accuracy of Determination of Relative Gravity by the Torsion-Balance."* In the case

* Bulletin of the American Association of Petroleum Geologists (Volume 16, p. 1325).

of the torsion-balance, as shown by Barton, the accuracy with which the gravity difference between two stations can be obtained depends on their distance apart, becoming less as the distance is increased. In fact the probable error is proportional to the square root of the distance, being given by Barton as 0.39 millidyne for a single traverse 10 kilometers in length. These loops average the rather large length of 42 kilometers on this survey since it is a primary net-



CLOSURE DATA

TOTAL GRAVITY DIFFERENCE, MILLIDYNES	NUMBER OF DIFFERENCES IN LOOP	ERROR OF CLOSURE, MILLIDYNES
17.07	4	0.19
15.20	3	0.26
14.90	4	0.11
15.65	5	0.03
6.05	4	0.05
8.67	3	0.23
6.48	3	0.16
8.16	4	0.04

AVERAGE ERROR OF CLOSURE = 0.13 MILLIDYNES

PROBABLE ERROR OF CLOSURE = 0.11 MILLIDYNES

BARTON GIVES FOR 45 TYPICAL TORSION-BALANCE LOOPS, P.E. OF CLOSURE = 0.39 MILLIDYNES PER 10 KILOMETER LENGTH OF LOOP. T.B. ERROR PROPORTIONAL TO SQUARE ROOT OF LENGTH OF LOOP. OUR LOOPS AVERAGE 42 KM LENGTH. HENCE T.B. AVERAGE P.E. ON THIS SURVEY WOULD HAVE BEEN 0.80 MILLIDYNES. ACC. FACTOR=7.3

OUR TYPICAL DETAIL NETWORK LOOPS AVERAGE 3 KM LENGTH. OUR ERROR=0.11 MILLIDYNES. FROM BARTON, T.B. ERROR FOR LOOP OF SAME LENGTH = .2 2 MILLIDYNES. ACCURACY FACTOR = 2.0

FIG. 5. Comparison of the accuracy of the gravity-meter and the torsion-balance.

work to which detailed work was connected. The torsion-balance error would thus have been 0.80 millidyne, giving the gravity-meter an accuracy 7.3 times greater. Of course this comparison, as far as we have gone, is not entirely fair because the torsion-balance will show up much more favorably when dealing with smaller distances. In our usual detail work, we place stations one-half to one mile apart. We may then take the distance around a triangular loop to be about three kilometers. To make the comparison for a loop of this length we note that the gravity-meter error will not be appreciably affected by

the reduction in distance, while the torsion-balance error, according to Barton will be about 0.22 millidyne. Thus the meter still appears to be about twice as accurate. These considerations indicate quite clearly that the gravity-meter should be very much more reliable on the large scale surveys which are needed to detect deep-seated structures. It is evident that a structure whose center of gravity, so to speak, is at a depth of three miles or so will produce a gravitational anomaly which falls to half value at not less than one and one half miles from the center. Thus to include the whole anomaly, an area approximately five miles in diameter will need to be surveyed, and to be able to detect such an anomaly an even larger undisturbed region around it must also be included. In surveys of this scale, the gravity-meter must certainly be superior to the torsion-balance.

Another advantage of the gravity-meter, previously alluded to, is that it is less sensitive than the torsion-balance to nearby disturbing masses. To show that this is true in an exact general quantitative manner is difficult, though it is easy to understand in a qualitative manner. The difference is caused by the fact that the effect of a mass on a torsion-balance decreases inversely as the cube of the distance while for the gravity-meter it goes inversely as the square. Thus a mass which gives comparable effects on the two instruments, say one Eötvös unit on the torsion-balance, one tenth millidyne of the meter, when at some fairly large distance will produce an enormously greater effect on the balance than on the meter when brought to the vicinity of the instruments. To illustrate the difference further two typical simple cases have been calculated. The essential facts are given in Fig. 6. Case 1 deals with the effect of a thin layer of greater density at or near the surface such as a layer of gravel or other material denser than the normal soil. The thickness has been taken as two meters, the density 2.1 as compared to 2.0 for normal soil. Only the difference in density, however, is of importance. This layer is supposed to begin as shown and extend for considerable distance forward, backward, and to the left. Both instruments have been placed at the worst position for each, which does not happen to be the same position. For the balance, the maximum gradient is experienced when set up directly over the edge of the bed as shown. For the meter, the least favorable place is over the bed far removed from the edge. The calculated effect on the balance is 14 Eötvös units of gravity gradient. This is a very large effect, being 7 times the probable error of the balance if this is taken to be two Eötvös units. On the other hand the effect on the meter is

not measurable, being considerably less than its probable error, which may be taken as about one-tenth millidyne for this purpose.

A second case of interest is the effect of a nearby boulder, which for simplicity has been taken as a sphere just buried underground, having a diameter of four meters and a density differing from the surrounding soil by 0.5 grams per cubic centimeter. Again both instruments have been placed at their respective least favorable positions,

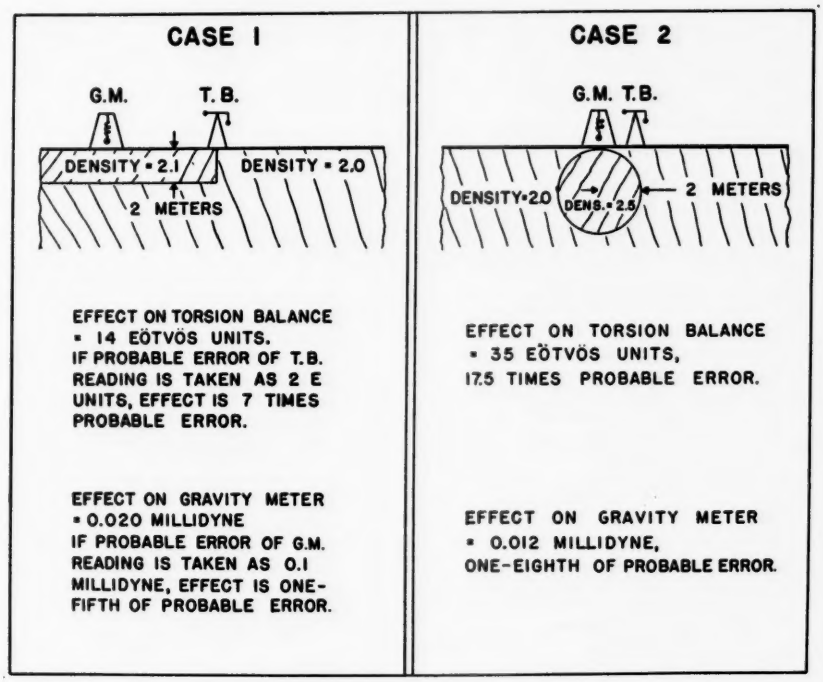

CASE 1
G.M.
T. B.
DENSITY = 2.1
DENSITY = 2.0
2 METERS
EFFECT ON TORSION BALANCE = 14 EÖTVÖS UNITS. IF PROBABLE ERROR OF T.B. READING IS TAKEN AS 2 E UNITS, EFFECT IS 7 TIMES PROBABLE ERROR.
EFFECT ON GRAVITY METER = 0.020 MILLIDYNE IF PROBABLE ERROR OF G.M. READING IS TAKEN AS 0.1 MILLIDYNE, EFFECT IS ONE-FIFTH OF PROBABLE ERROR.
CASE 2
G.M. T.B.
DENSITY=2.0
DENS.=2.5
2 METERS
EFFECT ON TORSION BALANCE = 35 EÖTVÖS UNITS, 17.5 TIMES PROBABLE ERROR.
EFFECT ON GRAVITY METER = 0.012 MILLIDYNE, ONE-EIGHTH OF PROBABLE ERROR.

FIG. 6. Comparison of the effect of disturbing masses on the gravity-meter and on the torsion-balance.

which in this case puts the balance somewhat to the side of the boulder, the meter directly above it. Again we see that in terms of the probable errors of the instruments the balance experiences an enormous effect, the meter an inappreciable one.

This kind of behavior is characteristic and seems to show definitely that the gravity-meter should be capable of obtaining valuable results in regions where shallow irregularities of density would make torsion-balance work practically worthless. To test the above theory,

it would be highly desirable to have an actual field comparison of the two instruments in such a region, but unfortunately this type of data is not available.

The foregoing may be summarized as follows: The gravity-meter, an instrument which measures gravity differences directly, has now been developed to the point where it it is superior to the torsion-balance in several important particulars for the prupose of making gravitational surveys. Its superiority rests on three circumstances. First, it is able to survey a given area with sufficient detail for most petroleum surveys in about one-third the time if we consider crews of comparable size and cost. Second, the accuracy will be better by a factor of two or more, the advantage becoming greater as the size of the survey is increased. Finally, the gravity-meter is much less affected by local terrain irregularities. This makes it possible to operate on the roads instead of having to find a suitable spot, as is the case with the torsion-balance. It also enables the gravity-meter to do more reliable work in most areas and very much better work in poor areas.

THE EFFECT OF MOISTURE ON THE DIRECT CURRENT RESISTIVITIES OF OIL SANDS AND ROCKS

J. J. JAKOSKY[1] AND R. H. HOPPER[2]

ABSTRACT

This paper contains the results of detailed research study to determine the factors which govern the electrical conductivities of oil sands and rocks. The experimental work shows the electrical resistivity to be an inverse function of the percentage of conductive water present in any rock type. It was found that the resistivity-moisture curve of both petroliferous and non-petroliferous rock are of a general hyperbolic form. For the higher values of moisture content, the curves rapidly approached the conductivity of the electrolyte contained within the rock or oil sands, while for the lower values of moisture content the resistivity values are high and governed by the properties of the rock. Rocks containing soluble salts have critical points on their resistivity-moisture curves, with the greatest change occurring in the neighborhood of ten per cent moisture content. Rocks containing fresh water have relatively high resistance values which change fairly uniformly with the variations in moisture content. The research work indicates that the presence of oil does not appreciably effect electrical resistance of the rock. Since the resistivity values are dependent upon the electrolytic effect, the work indicates that resistivity values alone are not a reliable criterion for predicting the presence or absence of an oil sand. The work explains further why high electrical resistivity values are not to be expected when applying electrical geophysical methods for mapping subsurface structure.

INTRODUCTION

In connection with research investigations conducted during the past few years on high and low frequency alternating current methods for differentiating the strata traversed by a drill-hole, it was noted that direct current electrical resistivity measurements did not give conclusive evidence regarding the presence of an oil sand or oil impregnated zone. In many instances it was found that productive oil sands did not give decisively high resistivity values, while in other cases the expected high resistivity values were obtained. Continuation of these studies indicated that the direct current resistivities were greatly affected by the percentage and chemical nature of water present in the oil sand. Comparison of the results of these studies with data obtained by a previous investigation[3] of the electrical conductivities of various water-bearing non-petroliferous earth materials brought out a close similarity in the curves showing per cent of moisture versus electrical resistivity. The experimental work shows the

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[3] J. J. Jakosky, C. H. Wilson, and R. N. Anderson, "The Electrical Properties of American Ores, Minerals, and Rocks." Unpublished thesis, University of Utah (1928).

resistivity to be an inverse function of the percentage of conductive water present in any type rock.

The work described in this paper was initiated by the senior author, who designed the apparatus and generally supervised the laboratory measurements. The junior author obtained and cut the necessary rock test specimens and conducted the impregnation and electrical measurements in the oil sand investigation. This phase of the work was pursued in cooperation with the Department of Geology of the University of California at Los Angeles, and the authors desire to acknowledge the cooperation of Dr. Wm. J. Miller and Dr. E. K. Soper of this department and of Mr. W. E. Mason of the Department of Mathematics of the same University. The crude oil and oil-field water used in the investigation were furnished by the Union Oil Company, and acknowledgment is made of the helpful suggestions given by Dr. H. W. Hoots, Mr. Edmund Jussen, and Mr. H. C. Pyle of that company during the course of the studies. The experimental work on earth materials other than oil sands was carried out in a manner similar to the oil sand investigation, with the laboratory measurements conducted largely by Mr. C. H. Wilson, and special acknowledgment is due him and Dr. D. A. Lyon, formerly Director of the Department of Metallurgical Research, University of Utah.

FACTORS GOVERNING THE RESISTIVITIES OF OIL SANDS

It is well recognized that the conductivity of practically all nonmetallic materials comprising the earth's crust is very low when these materials are dry. The previous work[3] on the resistivities of various rock types showed that these materials are very poor conductors (in fact almost perfect insulators) when dry, and that their conductivity is a function of: (1) the percentage of moisture disseminated through the material, (2) chemical properties and ionization factors of the soluble salts in the material and (3) the nature of the rock material itself.

Since crude oil is an almost perfect insulator against electrical current, it might be expected that a porous rock containing oil would have a very high resistivity. Practically all oil reservoir rocks, however, contain both oil and water in their pores,[3a] and the presence of dissolved salts in this water tends to lower the resistivity of the rock.

[3a] H. C. Pyle and T. H. Jones, "Quantitative determination of the connate-water content of oil sands," Oil & Gas Journal, Nov. 12, 1936. Paper delivered at 17th annual meeting, American Petroleum Institute, Los Angeles.

The ability of some of the connate waters to remain in the pores of a rock during and after the displacement of much of the connate water by oil may be explained on the basis of the differing surface tensions of the two fluids. The surface tension of water is about three times as great as that of oil, and therefore, by capillary action, water tends to be drawn into narrower crevices than does oil. Hence when oil attempts to dislodge water from the pores of a rock it may readily displace (by mechanical or hydraulic action) the water in the large central portions of the pores, and yet the water in the narrow corners of the pores may remain in place (due to surface tension and adsorption phenomena) during the movement of the oil into the reservoir rock and after the oil has come to rest in it.

Judging from several lines of evidence, the amount of connate water remaining in a sand after the invasion of the sand by oil may be considerable. Lindtrop and Nikolaeff, in their studies on the Grozny oil sands,[4] forced crude oil through glass tubes filled with water-saturated sand until clean oil came out at the outlet ends of the tubes, and, as a result of 28 tests with sand having an average theoretical porosity of 38 per cent, the average amount of water remaining in the sand after clean oil was flowing out of the outlets of the tubes was 18.2 per cent of the pore-volume of the sand. The same authors mined samples of the oil sand in the Shubaninskaya Gallery of the Baku district, and determined their average water content as 12.1 per cent of the pore-volume. These samples obtained by mining gave more reliable results in water-content determinations than would cores of oil sands, as the possibility of contamination by drilling fluids was eliminated. Also, electrical logging operations in oil wells have shown in certain fields that the resistivity of the producing sand of a given field varies from place to place, the highest resistivities being found on the structural highs,[5] and these changes in resistivity are presumably due to variations in the moisture content of the producing sand.

The purpose of the oil sand investigation described in this paper was to determine the relations between variations in the resistivities

[4] N. T. Lindtrop and V. M. Nikolaeff—"Oil and Water Content of Oil Sands, Grozny, Russia." Bulletin of the American Association of Petroleum Geologists, Volume 13,—811–822 (1929).

[5] C. and M. Schlumberger, and E. G. Leonardon—"A New Contribution to Subsurface Studies by Means of Electrical Measurements in Drill Holes." Technical Publication No. 503 of the American Institute of Mining and Metallurgical Engineers, pp 13–15 (1933).

and the oil and water content of the sands. Briefly described, this investigation consisted in the impregnation of blocks of sandstone with oil-water emulsions and in the measurement of the resistivities of the impregnated blocks. Additional data are included, for comparative purposes, showing the variation of resistivity with moisture content for certain rocks and fault gouges.

DESCRIPTION OF APPARATUS FOR OIL SAND STUDIES

IMPREGNATION APPARATUS

Preliminary study indicated that the most effective method of bringing about the complete saturation of a block of sandstone by an oil-water emulsion was to dehydrate the block at 105°C. in a vacuum, and then to admit the emulsion into the container holding the block, applying pressure to the system and forcing the emulsion into the evacuated pores of the sandstone. In order to carry out this procedure, the apparatus shown in Figures 1 and 2 was built.

The stirring apparatus A (Fig. 1) consisted of a cylindrical glass tank in which a rod with paddles attached was rotated by a small electric motor. This apparatus was used to keep the emulsion agitated while the evacuation was going on, the emulsion having been made previously by mixing the proper volumes of oil and water. Adjacent paddles on the stirring rod were bent at the ends so that by rotating the rod the liquid was forced in the tank in opposite directions, either up or down, after the manner of opposing screw propellers. In this way thorough mixing was accomplished and any settling out avoided. The stirring tank was connected with the storage tank *B* by standard $\frac{1}{4}$ inch iron pipe and heavy rubber tubing. The compressed-air line *C* entered the system between the two tanks.

The storage tank consisted of a section of 3 inch pipe with reducers at each end. Its function was merely to act as a pressure reservoir for the emulsion while pressure was being applied. Pipes leading from the bottom of the storage tank were equipped with valves which could close off the bottom of the storage tank and disconnect the evacuating apparatus while the pressure was being applied.

The pressure cylinder *D* held the rock during drying, evacuation, and impregnation. It consisted essentially of a short section of 5 inch pipe with a square bottom welded on one end and a square cover of the same size fitted to the other end by means of a circular groove and a gasket. Four bolts running from the bottom through corresponding holes in the cover at the corners of the squares were used for fastening

the cover; nuts above the cover being screwed down to secure a tight fit. The bottom was tapped for a $\frac{1}{4}$ inch discharge pipe.

The pressure cylinder piping contained a union which allowed it to be swung into the electric oven *G* during the drying, evacuation, and impregnation steps. A pressure gauge *F* registered impregnation pressures.

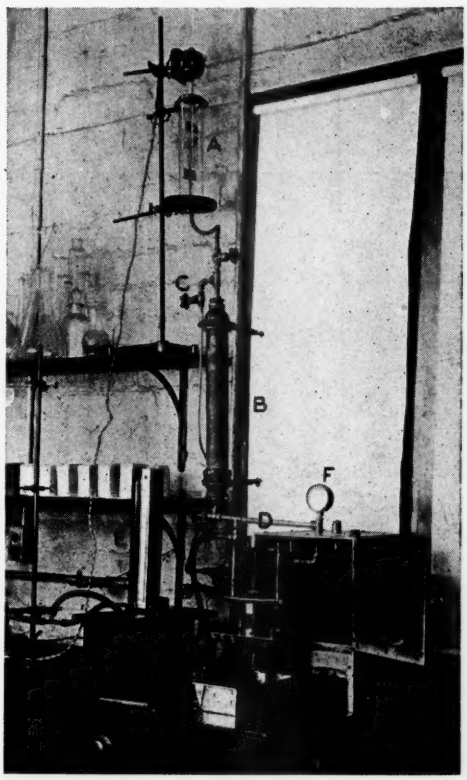

FIG. 1. Apparatus set-up for impregnation tests.

The evacuating apparatus consisted of an electrically driven Synco-Nelson vacuum pump. A glass trap-bottle was used to catch the water which condensed in the pipes during the drying process, and also to catch any emulsion which might be left in the pipes from the preceding run. The mercury manometer *E* was of the ordinary closed-tube type, graduated in millimeters.

ELECTRICAL APPARATUS

The complete apparatus for determining the electrical resistivities of the rock specimens is illustrated in Fig. 2. At the left of this figure is the resistivity-measuring instrument; in the center is the specimen holder; and to the right is shown impregnated and original rock specimens. The method employed consists essentially in passing a direct current of known magnitude through the rock specimen and the measuring of the potential drop across the specimen. The apparatus incorporates proper circuit features for temperature corrections, thermoelectric potentials, electrochemical effects and variations of conductivity with current density.[6] The stand for holding the speci-

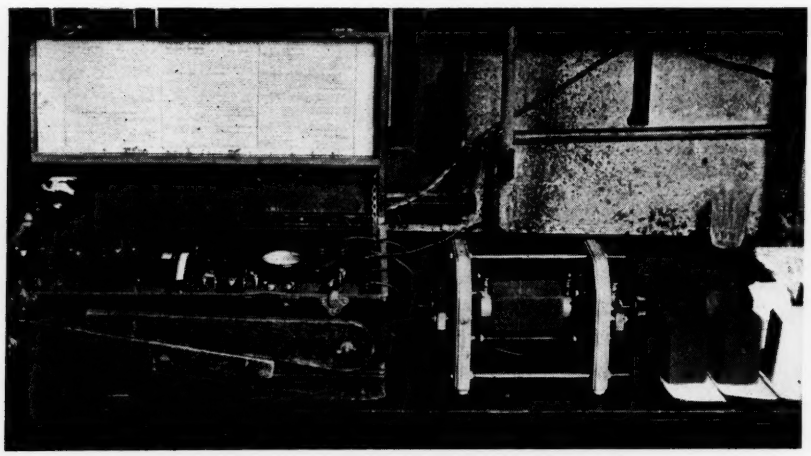

FIG. 2. Resistivity apparatus and specimen holder.

mens while measurements were being made is of the same general design as used in the prior investigations on rock samples.[3] Current was passed through the specimen between two circular-ring electrodes, contacting the specimen at the ends. This arrangement was adopted to secure uniform current density throughout the rock sample. Potential electrodes, located co-axially with the ring electrodes, made point-contacts at the centers of the ends of the specimen.

Fig. 3 is a schematic and simplified wiring diagram of the resistivity apparatus. A reversing switch 1 allowed the current to be passed through the specimen in either direction. A multi-range milli-

[6] J. J. Jakosky, U. S. Patents No. 2,015,401.

ammeter 3 was employed for measuring the current. A switch 4 was used to control the time of current flow.

The two potential electrodes, placed coaxially with the current ring electrodes, made contact with the ends of the specimen. A re-

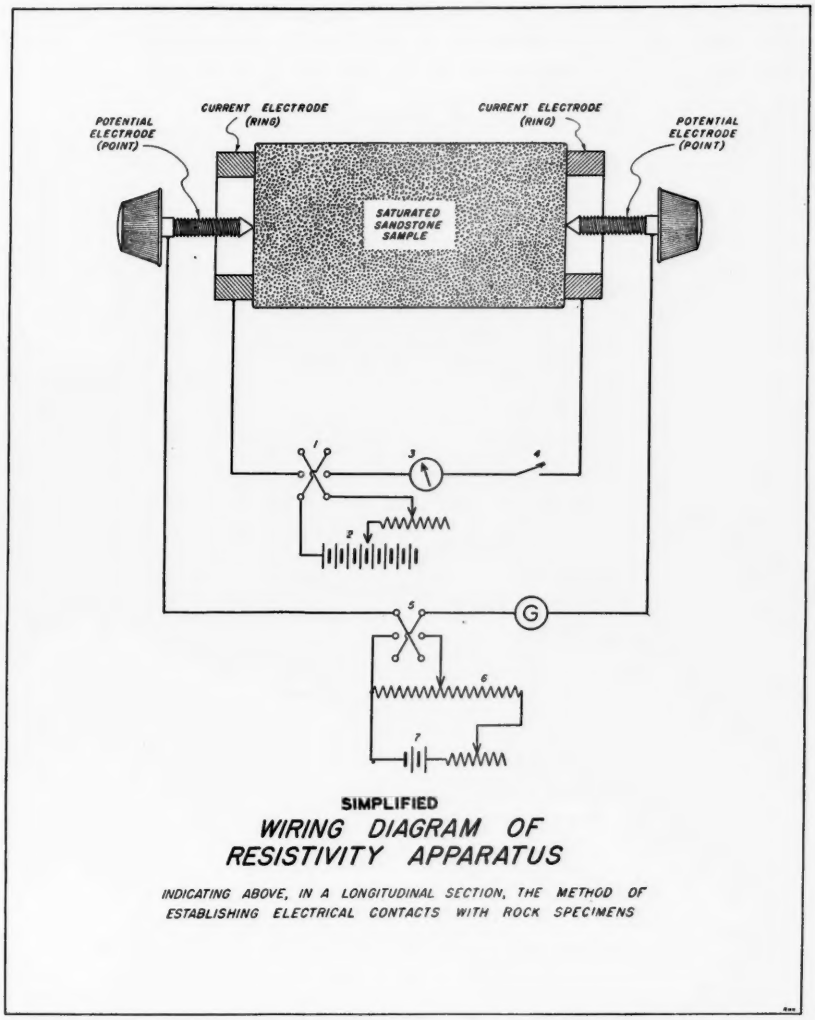

FIG. 3

versing switch 5 connected to the potentiometer 6 was employed for reversing the potentiometer in accordance with the reversal of current in the power circuit. A battery power supply 7, adjusted to constant

potential by means of a standard cell, furnished the potential drop across the resistor 6. The potential values for various positions of the slider on the resistor were known from a prior calibration with a standard potentiometer. A sensitive galvanometer G was employed for determining the null-point.

In practice, the switch 4 was open and the potentiometer 6 was adjusted until the galvanometer read zero current. Switch 4 was now closed and the simultaneous values of the potential and the current, after a given short-period interval, and followed by duplicate check measurements, were then recorded.

The fundamental formula used for calculating the resistivity of material is as follows:

$$R=\frac{AE}{LI} \tag{1}$$

In which A = cross-sectional area of specimen, in square centimeters

L = length of specimen, in centimeters, between the potential electrodes.

R = resistivity of specimen, in ohms per centimeter per square centimeter, or centimeter-ohms.

E = potential drop across specimen, in millivolts.

I = current flowing through specimen, in milliamperes.

DESCRIPTION OF MATERIALS USED FOR OIL SAND STUDIES

WATER

The water which was used in this experiment was obtained from the Union Oil Company's Carson No. 4 Well in the Dominguez, California, field. A chemical analysis of this water gives,

Radical	*Parts per Million*
Na^+	10,383
Ca^{++}	624
Mg^{++}	246
So_4^{--}	0
Cl^-	17,730
Co_3^{--}	0
HCO_3^-	190
Total	29,173

From this analysis it can be seen that the salinity is almost entirely due to chlorides and that sodium is the chief positive radical. This is true of all of the waters from the Dominguez wells.

The specific gravity of this water was determined by the pycnometer method to be 1.024.

OIL

The crude oil used in this investigation was also obtained from the Dominguez field, from the Union Oil Company's Callendar No. 28 Well.

Tested by the pycnometer method, the specific gravity of this oil was found to be 0.861, corresponding to a gravity of 32.8° A.P.I.

EMULSION

In order to make a mixture of oil and water to be used for impregnating the rock samples, the proper volumes of oil and water to give the desired percentage of oil in the emulsion were poured into a beaker and beaten thoroughly with an egg-beater for five minutes. The resulting temporary emulsions were found to require varying lengths of time before any settling out of the constituents was visible, depending upon their compositions. In all cases, however, a lapse of time of at least 30 minutes after the mixing was necessary before a layer of water 2 millimeters thick had formed at the bottom of the beaker.

In order to determine the degree of saturation of the sandstone blocks in this investigation it was necessary to ascertain the density of each emulsion. Knowing the specific gravity of the oil and the water, the density of the emulsion was determined from the following equation:

$$D=\frac{p_0}{100}d_0+\frac{p_w}{100}d_w \qquad (2)$$

In which p_0 = per cent oil in the emulsion
p_w = per cent water in the emulsion
d_0 = specific gravity of the oil (0.861 at 20°C.)
d_w = specific gravity of the water (1.024 at 20°C.)
D = density of the emulsion, grams per cubic centimeter.

SANDSTONE

General Description. The sandstone used in this investigation was taken from a member of the lower Modelo formation in the Santa Monica Mountains.[7] It is best exposed in a road-cut on the south side

[7] H. W. Hoots, "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California." USGS Prof. Paper No. 165-C. plate 16, (1931).

of Mulholland Highway (N latitude 34°07′49.50″, W longitude 118°28′51.51″) where it outcrops as a bed about six inches thick which dips gently toward the north.

The rock is light buff in color, rather friable, and not very well sorted. The size of the grains ranges up to two millimeters in diameter. From a megascopic examination of its mineral content it is evident that quartz is the predominant constituent, although dark-colored grains of other minerals and flakes of mica are fairly abundant. The cement is light brown and apparently consists chiefly of limonite.

Microscopic Description. Corroborating the megascopic examination, a study of a thin-section of the sandstone under the microscope showed that the sandstone used in this experiment is composed chiefly of quartz. At least 70 per cent of the area of the section is made up of this mineral. Acid oligoclase, biotite, hornblende, and orthoclase, named in the approximate order of their abundance, are the chief minerals which constitute the remainder of the rock. Numerous small grains of magnetite and zircon are also present in the section, and one grain of a pale green isotropic mineral (garnet?) was observed. Several grains of the rock named the "Santa Monica slate" by Hoots were seen in the section. Limonite and silica form the cement, not very much of which is present in the rock.

Some of the orthoclase grains are slightly sericitized and several of the biotite cleavage fragments are somewhat bleached, but alteration of the minerals is, on the whole, not very pronounced. Most of the grains are decidedly angular, reentrant angles being common, and the degree of sorting is poor. These characteristics, together with the mineral content, cause the rock to be classified as an arkosic sandstone.

Size Analysis. After crushing, washing in dilute hydrochloric acid, rinsing with water, and drying, the following screen analysis of the sandstone was obtained:

SCREEN ANALYSIS OF SANDSTONE USED

	Screen Openings (mm.)	*Weight Retained, grams*	*Per cent Retained*	Σ *Per cent*
Retained on	2	0.2	0.1	0.1
"	1	2.2	1.4	1.5
"	1/2	12.3	7.7	9.2
"	1/4	24.7	15.5	24.7
"	1/8	47.6	30.0	54.7
"	1/16	37.2	23.4	88.1
Passed through	1/16	34.8	21.9	100.0
Totals		159.0	100.0	

The textural constants of this sandstone, following the method of Trask,[8] are: (1) median diameter, 0.14 millimeters, (2) coefficient of sorting, 3.12, and (3) coefficient of skewness, 1.02.

Roundness of the Grains. Using the Tickell method[9] of assigning a numerical expression to the degree of rounding of the grains, the average roundness number of a selected group of grains was determined to be 0.69.

Porosity. To determine the porosity of the sandstone the Melcher method was employed.[10] An initial test gave a figure of 22.37 per cent for the porosity. A second complete Melcher test on a sample about three inches distant from the first sample on the outcrop of the sandstone gave a porosity value of 24.02 per cent. The average of these two figures, 23.2 per cent, was assumed to be the porosity of all specimens in computing the degrees of saturation attained by their impregnation.

IMPREGNATION PROCEDURE

The sandstone samples were cut in the form of rectangular blocks of approximately the same size—about 5.0 by 5.0 by 9.5 centimeters—and the dimensions of each block were measured accurately to the nearest millimeter. The lengths of each of the twelve edges of each block were measured, and the values for the length, breadth, and thickness of each block, which are recorded in columns 2, 3, and 4 of Figure 4, were obtained by averaging the four suitable measured dimensions. The four measured dimensions did not differ from the average by more than one millimeter. Each of the blocks was cut so that its longest dimension was perpendicular to the bedding-planes.

The blocks were next thoroughly dried in an electric oven, the temperature being kept at 110°C. for sixteen hours. After removal from the oven, each block was cooled to room temperature and weighed.

At the beginning of the process of impregnating an individual sample, the pressure cylinder was cleaned and the sandstone block placed in it. The cover plate and the outlet were tightly closed, and the

[8] P. D. Trask, "Origin and Environment of Source Sediments Of Petroleum" pp. 70–74. Gulf Publishing Company (1932).

[9] F. G. Tickell, "The Examination of Fragmental Rocks," p. 6. Stanford University Press, (1931).

[10] A. F. Melcher, "Determination of Pore Space of Oil and Gas Sands," Transactions of the American Institute of Mining and Metallurgical Engineers, Volume 45, pp. 469–498, (1921).

pressure chamber was swung into the oven and the pipe union made tight, after which the vacuum pump was started and the electric oven turned on. The temperature in the oven was kept at approximately 105°C. for half an hour, with the vacuum pump running continuously during this period. Evacuation for this length of time reduced the

TABLE OF RESULTS

1 NUMBER OF SPECIMEN	2 DIMENSIONS Centimeters Thickness	3 Breadth	4 Length	5 WEIGHT DRY Grams	6 MIXTURE USED Percent by Volume Oil	7 Water	8 DENSITY OF MIXTURE Grams per cc	9 WEIGHT IMPREGNATED Grams	10 PERCENT OF VOIDS FILLED BY MIXTURE	11 CURRENT Milliamperes	12 POTENTIAL Millivolts	13 TOTAL RESISTANCE Ohms	14 RESISTIVITY Ohms per cm. per square cm.
1	5.2	5.1	9.0	455.2	100	0	0.861	502.0	98.1	Less than 0.01	More than 1000	More than 100,000	More than 250,000
2	4.8	5.1	9.5	441.1	95	5	0.869	486.0	95.9	0.05	530	10,600	27,370
3	5.0	4.8	8.9	409.9	90	10	0.877	450.9	94.2	0.12	462	3855	10,390
4	4.6	5.0	9.3	386.6	85	15	0.885	428.9	96.3	0.38	745	1962	4852
5	4.8	5.1	9.7	441.5	80	20	0.893	489.5	97.5	0.70	765	1093	2760
6	5.0	5.0	9.7	456.9	75	25	0.901	504.9	94.6	0.50	374	748	1928
7	5.1	5.3	9.3	471.4	70	30	0.909	524.8	100.8	0.91	528	580	1687
8	5.0	4.8	9.4	420.0	65	35	0.918	469.7	103.5	0.61	278	456	1163
9	5.1	5.3	9.2	440.0	60	40	0.926	493.0	99.2	0.68	208	306	899
10	5.3	5.0	9.3	456.6	55	45	0.934	509.1	98.3	0.68	188	277	788
11	5.1	4.8	8.8	415.6	50	50	0.942	462.8	102.5	0.67	171	256	710
12	5.1	5.0	9.2	433.5	45	55	0.950	484.9	99.4	1.28	280	219	606
13	5.2	4.7	9.1	417.8	40	60	0.958	465.5	96.7	1.61	328	204	557
14	5.3	5.0	9.4	455.0	35	65	0.967	511.5	100.5	2.00	288	144	406
15	5.1	4.9	8.9	460.4	30	70	0.975	514.0	95.7	2.37	340	143	362
16	4.7	4.8	9.4	408.4	25	75	0.983	454.5	95.4	2.87	368	128	308
17	4.7	4.5	9.1	367.2	20	80	0.991	410.9	98.9	4.21	437	104	241
18	4.7	4.2	9.2	352.9	15	85	0.999	396.1	102.7	4.48	390	87.1	187
19	4.9	4.2	9.3	391.3	10	90	1.007	438.8	106.8	3.01	241	80.1	177
20	4.7	4.9	8.8	390.3	5	95	1.015	437.0	97.9	8.30	475	53.4	140
21	5.1	5.1	9.7	480.1	0	100	1.024	536.2	97.2	10.50	512	48.8	131
22	5.1	5.0	9.6	459.0	97.5	2.5	0.865	510.5	104.1	0.02	620	31,000	82,400
23	5.2	4.9	8.8	404.6	92.5	7.5	0.873	449.3	98.6	0.08	565	7060	20,460
24	5.1	4.7	9.0	376.4	87.5	12.5	0.881	420.4	99.6	0.04	100	2500	6667

FIG. 4. SUMMARIZED DATA TABLE

pressure in the cylinder containing the sandstone block to one or two millimeters of mercury. The evacuation of the sample and the application of heat to it were always continued for at least half an hour after the last water had been observed to fall into the trap, so that the pressure cylinder contained a totally dry block of sandstone in an almost complete vacuum.

The emulsion with which the particular sample was to be impregnated was next mixed. The total volume of emulsion in each case was 500 cubic centimeters, and the emulsion was made by pouring the required amounts of oil and water into a beaker and mixing vigorously and thoroughly with an ordinary egg-beater. This mixture was then poured into the stirring tank, the stirring paddles being rotated slowly (about 200 revolutions per minute when all of the 500-cubic centimeter charge of emulsion had been pured into the tank) during the pouring. The only purpose of the stirring unit was to keep the emulsion agitated until the time of its entrance into the storage tank; however, the mixing of the emulsion with the egg-beater was always timed so that the emulsion was never in the stirring tank for more than half a minute. The stirring paddles were rotated slowly so as to minimize any tendency toward centrifugal separation of the oil and water emulsion.

The proper valves were manipulated and the emulsion was next rapidly drawn into the storage tank by the vacuum below it and the atmospheric pressure above.

Immediately after, the emulsion was forced into the pressure cylinder containing the rock, and an external air pressure of 80 pounds per square inch applied. To this 80-pound gauge pressure must be added an atmospheric pressure of approximately 14.7 pounds per square inch, since the rock was initially in a vacuum; thus the emulsion was forced against the surfaces of the sandstone with a pressure of approximately 94.7 pounds per square inch.

It was determined by experimenting with several samples that application of this pressure for half an hour was sufficient to fill the voids of a sample almost as completely as if subjected to the pressure for eight hours. It was also found that, although different emulsions had different degrees of permanency, practically no settling out of the water in any of the emulsions was visually noticeable half an hour after mixing. Consequently the samples used in the final runs were left in their emulsions under pressure for thirty-minute periods.

At the end of the half-hour period the impregnated rock was removed from the pressure chamber. After the emulsion had been wiped from its surfaces the block was weighed, as recorded in column 9 of Fig. 4.

Although the oven had been turned off half an hour previously, the temperature of the rock was still several degrees Centigrade above room temperature. The rock was allowed to cool for a short period of

time until room temperature had been reached before it was placed in the specimen-holder of the resistivity apparatus. This procedure was necessary because of the variation of resistivity with temperature.

The electrical resistivity was determined in the manner already described. At least three sets of current and potential readings were taken for every block, and the average values of these quantities for each sample are given as columns 11 and 12. The total resistance and the resistivity were calculated and are listed in columns 13 and 14 of Fig. 4.

Column 10 lists the per cent of the pore-space of each specimen that was filled by the emulsion with which it was impregnated. The method of obtaining these values is given below.

If w_d = weight of the specimen, dry, in grams
w_w = weight of the specimen, impregnated, in grams
D = density of the emulsion, in grams per cubic centimeter (found by equation (2) and recorded in column 8.
L = length of specimen, in centimeters
b = breadth of specimen, in centimeters
T = thickness of specimen, in centimeters
P = porosity of the specimen, in per cent

then the per cent of the total pore-space of the specimen filled by the emulsion in the impregnation process, P_F, is

$$P_F = 100 \times \frac{w_w - w_d}{0.01P\ (DLbT)} \tag{3}$$

In applying equation 3, a value of 23.2 for P (the result of the Melcher porosity test) was used for all the specimens. This of course was only an average value of two determinations which could not apply exactly to each specific case; therefore some of the values of P_F, as might be expected, came out to be more than 100. The range of values of P_F was from 94.2 per cent to 106.8 per cent, with all other values lying between these limits. It can therefore be seen that the specimens were in all cases nearly saturated.

Fig. 5 consists of graphs showing resistivities plotted against emulsion compositions. The resistivities recorded in column 14 of Fig. 4 are plotted as ordinates, the corresponding abscissas being the proper values of emulsion compositions as taken from columns 6 and 7 of the same table. The vertical scale used for Curve A allowed all of the re-

sistivity determinations to be used in its plotting. Curve *B* is drawn with a magnified vertical scale but with the same horizontal scale as Curve *A*. The curve in the upper right-hand corner of the figure shows

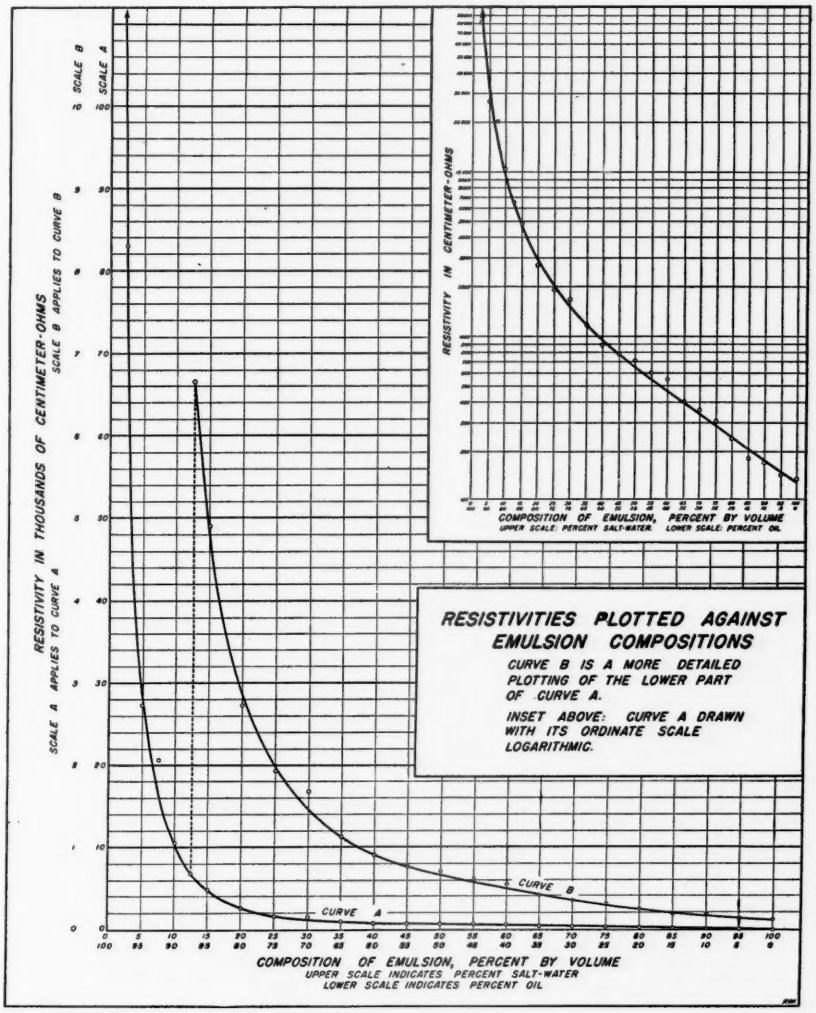
RESISTIVITY IN THOUSANDS OF CENTIMETER-OHMS
SCALE A APPLIES TO CURVE A
SCALE B APPLIES TO CURVE B
SCALE A
SCALE B
RESISTIVITY IN CENTIMETER-OHMS
COMPOSITION OF EMULSION, PERCENT BY VOLUME
UPPER SCALE: PERCENT SALT-WATER. LOWER SCALE: PERCENT OIL
RESISTIVITIES PLOTTED AGAINST EMULSION COMPOSITIONS
CURVE B IS A MORE DETAILED PLOTTING OF THE LOWER PART OF CURVE A.
INSET ABOVE: CURVE A DRAWN WITH ITS ORDINATE SCALE LOGARITHMIC.
CURVE B
CURVE A
COMPOSITION OF EMULSION, PERCENT BY VOLUME
UPPER SCALE INDICATES PERCENT SALT-WATER
LOWER SCALE INDICATES PERCENT OIL

FIG. 5

the divergence of the points actually plotted from the smooth curve drawn through them when a logarithmic ordinate scale is used.

These curves clearly bring out the fact that it is necessary for the

emulsion to be high in oil content before the increase in resistivity becomes very pronounced. The slope of Curve *A* from the point indicating zero per cent oil to the point indicating 65 per cent oil is relatively flat and practically constant. It is only for emulsions with oil contents in excess of 80 or 85 per cent that the increases in resistivity become important.

RESISTIVITY STUDIES ON OTHER ROCK TYPES[3]

In order to give comparative data for other rock types, the following abstract is included in this paper. This section of the paper describes studies conducted on several non-petroliferous rock types to determine the relationship between electrical resistivity and moisture content. In this work the total maximum moisture content was added to each rock sample and successively greater amounts of moisture were removed by heating. Direct current resistivity measurements were made after the removal of each increment of moisture. The heating was carried out at a very low rate and at as low a temperature as possible, since many rock substances are susceptible to decomposition at relatively low temperatures. After each heating or drying operation, the samples were allowed to reach equilibrium of moisture distribution, before the resistivity measurements were made. Referring to Fig. 6 the rocks from which curves No. 1 to 4 inclusive were derived are field specimens collected during work in northern Arizona.[11] Curve 5 is a specimen from southern Arizona,[12] and curves 6 and 7 are fault gouges from southern Utah.[3] The descriptions of the rocks used in these resistivity-moisture determinations are as follows:

Kaibab Limestone—Curve No. 1: This limestone is of Permian age. It is widely distributed over southern Utah and northern Arizona and caps the greater portion of the Coconino Plateau in northern Arizona. A typical section of the limestone consists of three members, a lower member consisting of buff colored alternating sandstone and limestone passing upward into more massive limestone; a middle member consisting of friable limey sandstone containing gypsum, and an upper member of light colored massive to slabby limestone with considerable chert.

The specimens used in the laboratory measurements were obtained from the lower Kaibab member exposed in the vicinity of

[11] J. J. Jakosky and C. H. Wilson, "Geophysical Examination of Meteor Crater, Arizona," AIMME Technical Paper, presented at the Feb. 1931 New York Meeting.

[12] Professional Report, International Geophysics, 1930.

Meteor Crater, Arizona. In this locality the rock is a thin-bedded impure, buff colored sandy limestone, containing considerable limonite in the form of a cementing matrix, and in concretions scattered irregularly through the formation.

Coconino Sandstone—Curve No. 2: This sandstone underlies the Kaibab limestone in the northern Arizona plateau region. It is of Permian age and consists of thick and thin bedded, white or grey, finely laminated, pliable, cross-bedded sandstone. The chief constituent mineral is quartz, in rounded, fine to medium sized grains, which have been cemented to a rock of considerable hardness, but which is still extremely porous. A few scattered limonitic concretions are seen in the sandstone. Some of the beds weather to a characteristic light brown or fawn color.

Supai Formation (Sandstone)—Curve No. 3: The Supai formation underlies the Coconino sandstone in the northern Arizona plateau region. It includes about 150 feet of thin-bedded limestones of Pennsylvanian age, approximately 1000 feet of alternating red, sandy shales, and red to buff colored sandstones of Permian age, and a top member consisting of about 300 feet of red shale of Permian age, and sometimes designated separately as the Hermit shale. The specimens employed in these measurements came from the central thick sandstone section. They are typically massive red sandstone.

Moencopie Shale (Shaly sandstone)—Curve No. 4: This formation overlies the Kaibab limestone in the vicinity of Meteor Crater, Arizona. It is of Triassic age; its contact with the underlying Kaibab marking the location of the Triassic-Permian unconformity in this area.

In the locality from which the specimens were collected, the rock consists of brownish red, to red, thin-bedded shales interbedded with massive and cross-bedded red sandstones. The specimens used in the measurements are typically impure shaly sandstone.

Altered Granodiorite—Curve No. 5: A complete series of alteration has been effected in this rock. The first stage, due to weathering, consisted of the change of the feldspathic constituents to sericite and calcite and the alterations of the ferro-magnesium minerals to chlorite. A second alteration, due to hypogene solutions gave a complete sericitization of the feldspars, with the complete leaching of the ferromagnesium constituents and a consequent increase in the porosity of the rock.

Clay Fault Gouge—Curve No. 6: This is a sticky, coherent, clayey

gouge, grayish brown in color, with local spots of brown oxide of iron. It is dominantly fine-grained in texture, appearing physically much like true clay. Fragments of broken rock occur in the mass, adding to its inhomogeneity. Chemically the rock is dominantly silica and alumina containing 59.6% of the former, and 33.8% of the latter, and it contains minor amounts of iron, magnesia, lime, and only a trace of sulphur. The analysis shows 3.2% of water soluble salts. The natural in-ground moisture content of the material is 21.5%.

Clay Fault Gouge—Curve No. 7: This sample is a coarse textured product of alteration in a fractured zone. It is dominantly silica, to the extent of about 85%, some of which is in the form of free quartz. It contains a maximum of 11% of alumina. Sulphur is present to the extent of 1.3% probably mostly sulphate; some of which is combined with calcium to form gypsum, and some probably existing as part of the sulphate of the soluble salt content, which is about 5.5%. The material is loosely cemented, and hence sandy in appearance and contains 14.5% natural moisture.

Effects of Soluble Salts on Conductivity: In order to obtain additional information regarding the mechanism of electrolytic conduction, it was decided to investigate the effect of soluble salts in the gouges.

The fault material of curve No. 6, containing 3.2% of water-soluble salts, and that from curve No. 7, containing 5.5% of water-soluble salts, were selected for the tests. These figures represent total water-soluble salt content, no quantitative separation or determination of the salts present having been made. Qualitative studies indicated that the salts are predominantly those of calcium, magnesium and iron, with possibly lesser amounts of sodium and potassium.

Samples of these gouges were boiled in beakers in distilled water for about two hours, the top water being decanted off several times during the treatment. At the end of this time the water suspension and solution was filtered through a suction filter and the residue allowed to dry until it reached a state in which it could be easily handled. It is believed that this treatment did not cause chemical change in the sample except that of removing the water-soluble salts. As regards physical properties, some change such as redistribution of the component grains, etc., may have occurred but this probably was not of major consequence as affecting electrical conductivity. By filtering, loss of slimes was avoided. After this treatment, resistivity-

moisture determinations were made on the samples in the customary manner. The results of these tests are shown in Curves 6*A* and 7*A*.

Graphs giving the relationship between direct-current resistivity and moisture content are shown in Fig. 6. It will be seen that the resistivity-moisture variations of these rocks and fault gouges is similar to that of the oil impregnated rock. The materials containing the greatest amount of dissolved salts (shales, gouges and the altered granodiorite) exhibit the sharpest changes in resistivity versus per cent moisture. A critical point for these materials occurs in the neighborhood of 10 per cent moisture. Above this moisture content the curves are relatively flat with slow change in values, while below this percentage of moisture the values increase sharply. The materials containing "fresh" waters which are low in salt content (sandstone, limestone and the leached gouges) have higher resistivity values and do not exhibit the sharp changes in resistivity as the per cent of moisture changes.

FACTORS GOVERNING CONDUCTIVITIES OF EARTH MATERIALS

Analysis of the curves clearly indicates that the flow of an electric current through rocks is by means of electrolytic conductivity. The current is carried by an electrolyte consisting of water solutions of various soluble mineral salts. The factors affecting this conduction are those that affect electrolytic conduction in general, although the effects of these factors may be modified by the artificial conditions imposed by such rock samples. It is important to note that the presence of oil in the oil-water emulsion tests did not appreciably affect the slope or magnitude of the curves as predicted by electrolytic conduction.

The theoretical basis of electrolytic conductivity is better known than is that of metallic conductivity. The essential facts are that the electrical current is conducted by the transfer of ions through the solution. These ions may be in part those of the solvent itself, but are mainly ions due to dissociation of the soluble salts forming the solute. The specific conductance of any solution will depend chiefly upon: (1) the concentration of the ions present, (2) their mobility, i.e., the velocity of their migration, and (3) their electrical charge. The concentration of the ions will depend upon the concentration of the electrolyte and upon its degree of ionization. With increase in concentration, the specific conductance will increase due to the larger

number of ions present, but generally reaches a maximum and then decreases due to smaller ionization and greater friction to the ionic motion, at the higher concentrations.

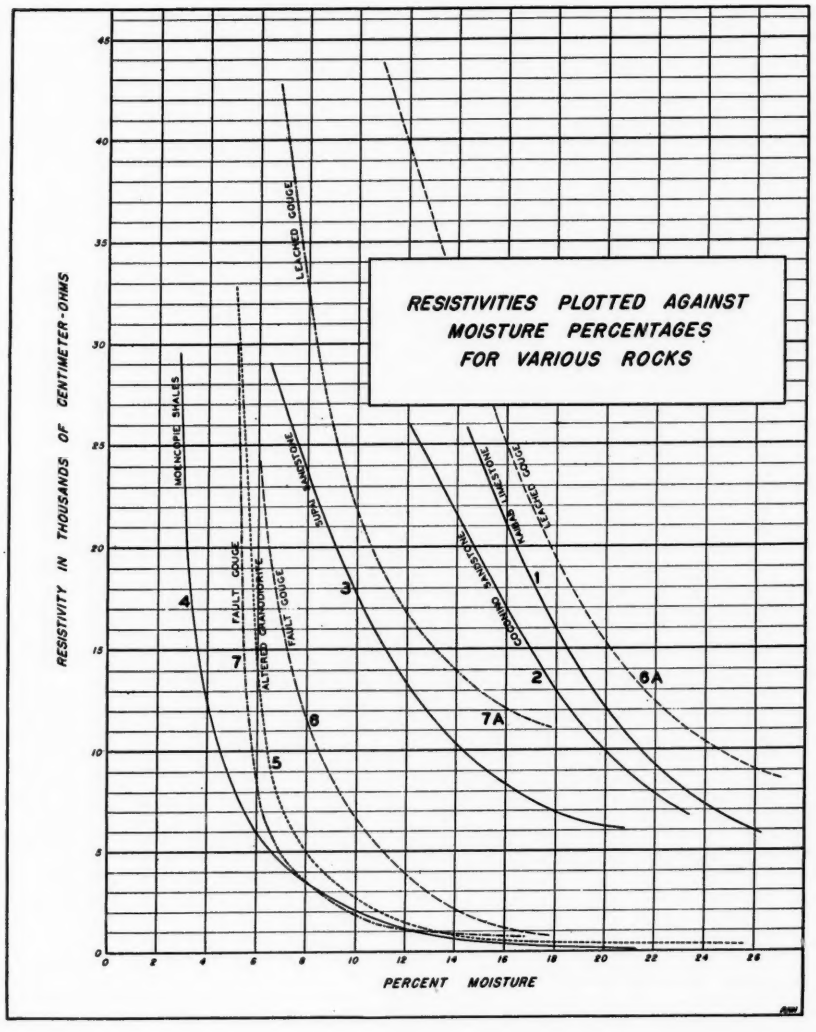

FIG. 6

The conductivity of an electrolyte increases with rising temperature, often very rapidly over the lower range of temperature. This is attributed to the decrease in viscosity of the solution, and the corresponding increase in the mobility of the ions. The rate of increase

of the conductivity becomes less as the temperature increases due to the rate of decrease in dissociation with the rising temperature. The effect of temperature on the conductivity of oil sands and adjacent rocks will be described in a subsequent paper dealing with tests on cores taken from California and Mid-Continent wells.

CONCLUSIONS

Since the chief purpose of this work was to obtain information which would be of use in the interpretation of electrical well logs of uncased and cased drill holes, the general conclusions from that viewpoint are briefly:

1. The resistivity-moisture curves of both petroliferous and non-petroliferous rocks are asymptotic to the two axes and of a general hyperbolic form. For the higher values of moisture content, the curves rapidly approach the conductivity of he electrolyte (moisture), while for very low values of moisture content the resistivity values are high and governed by the properties of the rocks.

2. Rocks containing soluble salts have critical resistivity values, with the change occurring in the neighborhood of 10 to 15 per cent moisture content. Less moisture than this produces high resistivity values, while higher percentages of moisture produce somewhat lower resistivity values.

3. Rocks containing "fresh" waters are of relatively high resistance values which change fairly uniformly with change in moisture content.

4. The presence of oil did not appreciably affect the electrical resistance of the rock. The resistance is governed almost wholly by the per cent and nature of the electrolyte contained in the oil bearing rock.

5. The interdependence of resistivity values on electrolytic effects shows that resistivity values alone will not be a reliable criterion for determining a rock type or predicting the presence of an oil sand. The subsurface electrolytic conditions in each oil field must be evaluated before such direct interpretation is made. It will be recognized however that this limitation of direct current resistivity measurements does not preclude the use of the conventional depth-resistivity logs for correlations between wells. Knowing the lithology in one well it is possible to correlate other wells in the same area by similar electrical characteristics occurring on the electrical logs of the various wells. However, variations in absolute values of resistivity, caused by lateral or vertical changes in moisture, or soluble salt content in the

strata, introduce complicating factors which must be considered before valid correlation or interpretation can be made.

DISCUSSION

R. D. WYCKOFF: The authors do not explain certain details in the technique of measuring with d.c. which would be of interest in view of the well-known difficulties usually encountered. Moreover, there are no data from duplicate observations given whereby the reader can judge the probable accuracy obtained. However, in view of the senior authors' wide experience in resistivity measurements this reviewer assumes that the question of technique is not involved in the results.

Some question does arise regarding the samples used in the tests. Whether the injection of an oil-water emulsion into a sand body actually results in a physical distribution of the component fluids within the pores simulating an actual oil sand is a highly debatable question. Because of well-known effects the oil globules will first selectively occupy the large pores and only after the percentage of water became very low would anything like a normal saturation by oil occur. It is the reviewer's opinion that the injection of oil into a water-saturated sand would more nearly approach natural conditions.

These points are mentioned because of some experience in determining the resistivity of sands as a function of water saturation. (Physics, Vol. 7, 9, pp. 327–328, Sept. 1936). While in this work the saturation was varied by different means and the resistivities were measured with 60 cycle a.c., the results show no erratic variations whereas if the results given in Fig. 4 of the present paper are plotted as per cent liquid saturation vs. per cent resistivity (or conductivity) using 100% water saturation as the initial resistivity reference point a rather erratic curve results. Moreover it does not agree with the writer's results (cf. ref. Fig. 2) except in the range from 0 to about 40% water saturation. And while the practical application of the results of the present paper probably lies within this range of agreement the comparison does raise the questions regarding experimental technique mentioned above.

J. J. JAKOSKY: The questions raised by Dr. Wyckoff are of special interest and are not discussed in the paper primarily due to our desire to save space, since the paper is already of considerable length.

Details of the technique for measuring the direct current resistivities are given in the patent cited in connection with the discussion of the electrical apparatus. The duplicate measurements usually checked within 1 per cent of each other, and such measurements have an accuracy well within practical limitations for this type of work.

Considerable study and consideration were given the method of impregnating the samples. It was first believed that there might be a selective filtration effect which would cause a partial break-down of the emulsion, as the emulsion penetrated the rock. Studies of impregnated samples of the rock indicated that the emulsion was stable enough to flow through the rock for the relatively short distance necessary. Random microscopic examination of a few of the impregnated rocks indicated a quite uniform distribution of the water-oil emulsion throughout the rock and there were no visible evidences of emulsion break-down or variation in oil-water content due to selective filtration. The sandstone used for these tests had relatively large pores and it is quite probable that had a finer-grained stone been used for the tests that some changes in emulsion content would have taken place.

In the early stages of the investigation some consideration was given the injection of oil into a water saturated specimen but no practical means seemed available for obtaining the proper percentage of oil and water, or of obtaining a uniform distribution of oil throughout the entire sample, by injecting oil into a water-impregnated rock. It appears to the writer that the larger the pores or interstices in a rock the more uniform will be the distribution of an oil-water mixture into such a material. This may account for the more uniform results obtained in Dr. Wyckoff's tests on the resistivity of sands.

The variation in results obtained in our present tests as compared to Dr. Wyckoff's tests, for percentages of water greater than 40 per cent, might possibly be explained by two factors; (1) the greater interstitial space of a sand as compared to the sandstone employed in the present tests, and (2) the greater instability of an oil-water mixture where the percentage of the water is greater than 40 per cent.

ABNORMAL VELOCITIES IN SEDIMENTARY BEDS IN EASTERN UTAH[1]

A. L. SMITH[2] AND JOHN H. WILSON[3]

ABSTRACT

Velocity determinations at wells and refraction shooting in the area indicate abnormally high velocities in Utah.

The following conclusions are reached: (1) these high velocities are related to hardening due to incipient metamorphism after deposition; (2) this condition has an adverse effect on the quality of reflections; (3) it interferes with interpretation of refraction data; (4) it may be an index of unfavorable condition for accumulation of oil or gas.

INTRODUCTION

This paper deals with the velocities found near the surface and in the wells in the vicinity of Cisco and Thompsons, Grand County, Utah; the location being shown on the accompanying index map (Fig. 1). Since the values found are abnormal and have a bearing upon the reliability of the interpretation of refraction work, it is believed that the data would be of interest to geophysicists.

Where volocities are mentioned in this paper, the rate of propagation of longitudinal sound or seismic waves is implied.

GEOLOGY OF THE REGION

The area with which this paper deals is situated in the central part of extreme eastern Utah, near the Colorado line, and is on the southern rim of the Uinta structural basin. The area lies along the margin of the old Pennsylvania land mass known as Uncompahgre or San Luis highlands, the Pennsylvania basin with its salt beds lying to the west, and the old land mass to the east.

The area has been subjected to considerable movement, the characteristic structure to the south and west being the structurally complicated salt anticlines involving flowage and intrusion of salt beds; while the usual type of structure to the north and east comprises relatively simple anticlines and faults.

The formations exposed in the area and with which this paper deals, vary in age from Cretaceous to Pennsylvanian.

[1] Published by permission of the Utah Southern Oil Company of Salt Lake City Utah.

[2] Independent Exploration Company, Houston, Texas.

[3] Colorado Geophysical Corporation, Denver, Colorado.

NEAR-SURFACE VELOCITIES

Velocities near the surface were determined at a number of points in several different formations incident to weathering and other refraction profiles. These data may be tabulated as follows:

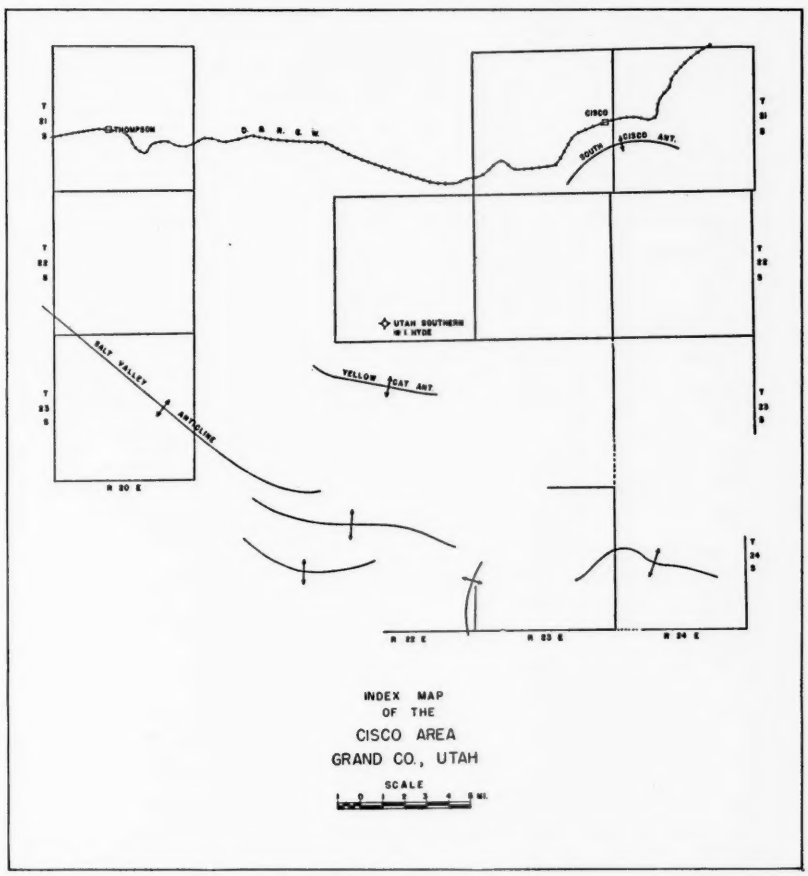

FIG. 1

TABLE I

Locality and Formation	*Velocity Determined*	*Estimated Normal Velocity*	*Percentage Increase over Normal*
Mancos shale (Cretaceous) west of Cisco, Utah...	13,500	7,200	87.5
Dakota sandstone (Cretaceous) on northwest flank of Yellow Cat Dome.....	9,850	6,800	45.0
Morrison formation (Comanchean or Jurassic) on northwest flank of Yellow Cat Dome.....	8,900	7,600	17.0
Paradox black shales (Pennsylvanian) on the axis of the Salt Valley anticline.....	9,900	8,000	24.0

It will be noted that the Mancos shales have a very abnormal velocity, but that the Morrison and Paradox shales are nearer normal, instead of having a greater velocity, as might have been expected from the exceedingly high velocity in the younger formation.

VELOCITIES IN WELLS

The Utah Southern Oil Company drilled their No. 1 Balsey on the axis of the Salt Valley Anticline. The well entered salt at 900 feet and continued in salt to the total depth of 6120 feet. The velocity in the salt was determined by shooting in the well and has been calculated as 16,200 feet per second, a normal value.

The Utah Southern Oil Company is now drilling their No. 1 Hyde on the northwest flank of the Yellow Cat structure, in search for shore-line sands of Pennsylvanian age.

In shooting this well, the usual apparatus was used; consisting of a geophone to be lowered in the well, measuring device for checking depth, together with cable for connecting geophone, and amplifying and recording unit.

The results of the volocity survey are shown in Fig. 2. As will be noted, the well log has been plotted alongside the velocity curve to show the relationship between velocity and stratigraphy. The vertical scale indicates the depth in feet, the horizontal scale the differential velocities. Shots were fired with the geophone at depths of 1100′, 1600′, 1975′, 2200′, 2700′, 3200′, 3700′, 4200′, and 4880′. The dashed lines represent the velocity determined for the indicated interval and the solid line connects the midpoints of these differential velocities, thus indicating approximately the average change in velocity.

The velocity from 1100′ to 1600′ is 10,380 feet per second—somewhat higher than normally would be expected from sands and shales of Upper Triassic age. The velocity from 1600′ to 2200′ in Moenkopi is 13,340 feet per second. This increase is probably due to the presence of some lime in the section. Below this point in the section, samples showed sands and shales, with a corresponding drop in velocity to about 12,500 feet per second to a depth of 2700 feet, which is below the top of the Cutler formation of Permian age. From 2900′ to 3700′ there is gradual increase, the velocity becoming 13,900 feet per second between 3200′ and 3700′; about such an increase as would be expected from the increase in depth. At this point, the velocity increase becomes very marked, the velocity between 3700′ and 4200′ being 15,560 feet per second, and from 4200′ to 4880′ being 17,900 feet per

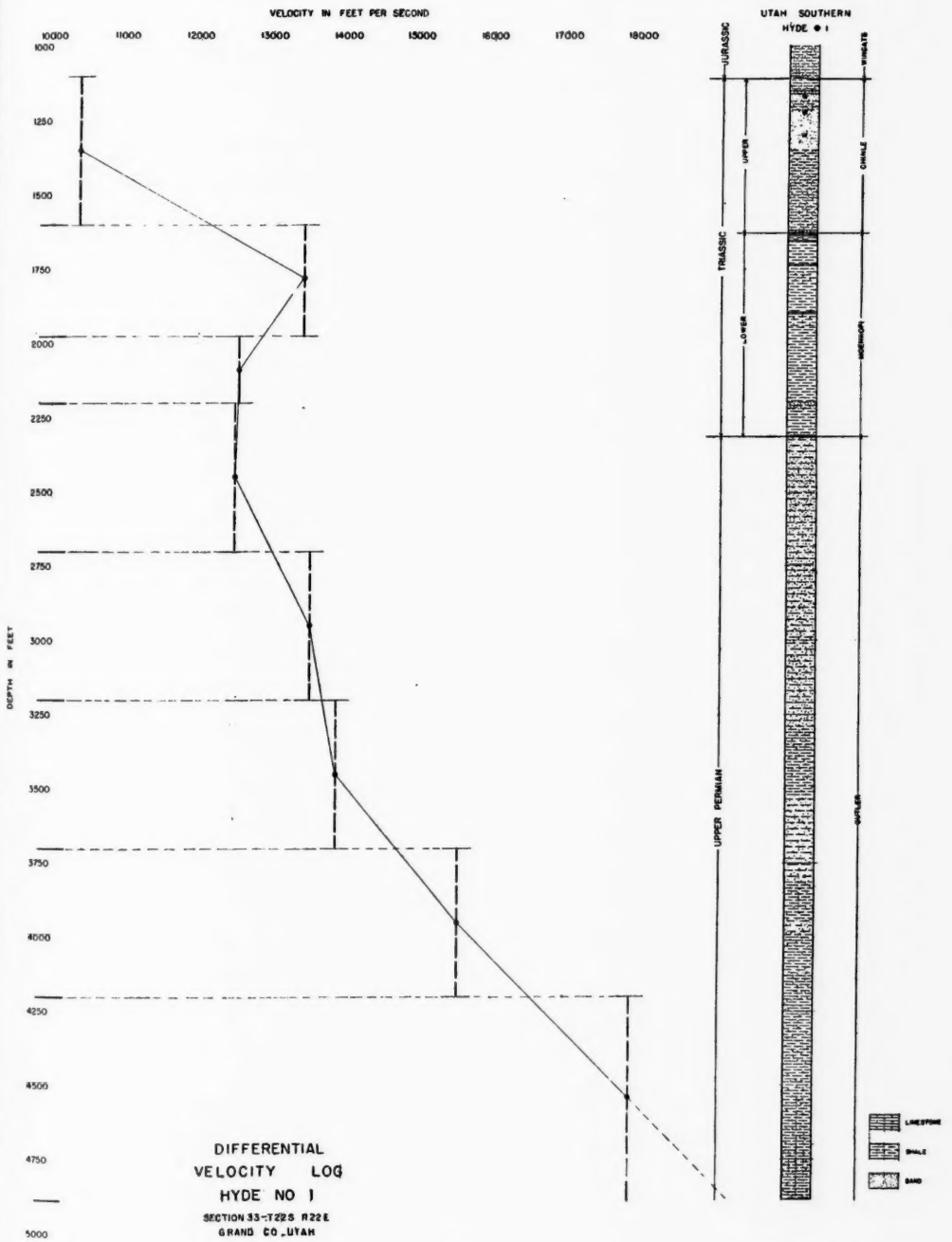
VELOCITY IN FEET PER SECOND
10000
11000
12000
13000
14000
15000
16000
17000
18000
1000
1250
1500
1750
2000
2250
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
DEPTH IN FEET
DIFFERENTIAL
VELOCITY LOG
HYDE NO 1
SECTION 33-T22S R22E
GRAND CO., UTAH
UTAH SOUTHERN
HYDE # 1
JURASSIC
TRIASSIC
UPPER
LOWER
UPPER PERMIAN
WINGATE
CHINLE
MOENKOPI
CUTLER
LIMESTONE
SHALE
SAND

FIG. 2

second. As this increase approximates a straight line, the velocity at the bottom of the hole probably approximates 18,600 feet per second. This is about the velocity found in limestone.

As will be noted from the well log, there is no change in sedimentation from 2300 feet down, the section consisting entirely of arkosic

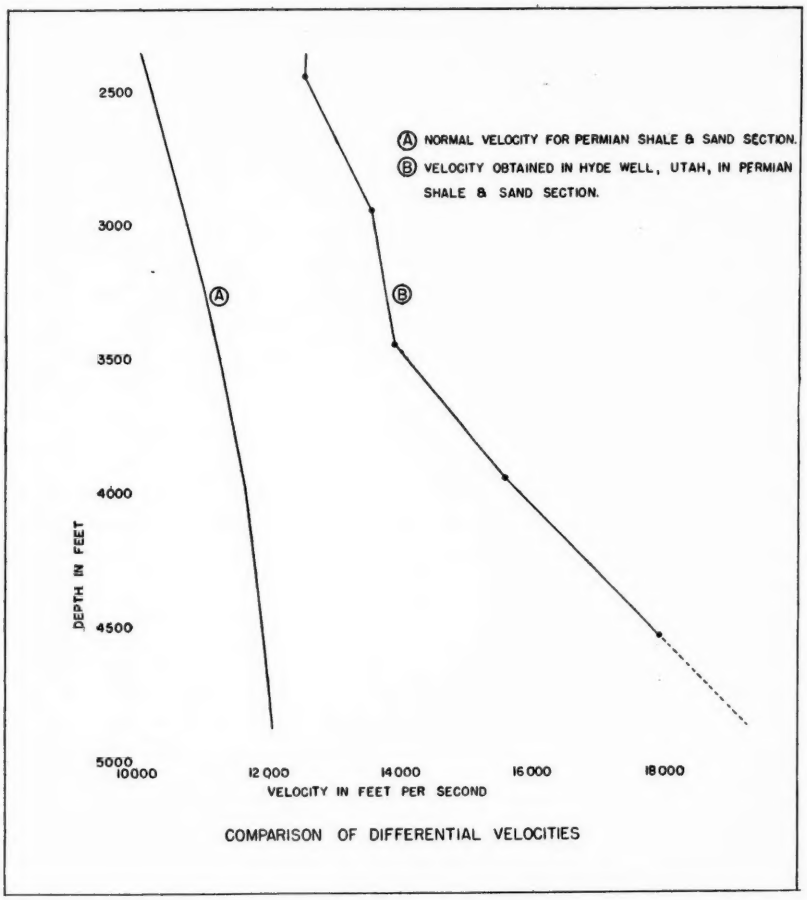

FIG. 3

sands and shales. As far as could be noted macroscopically, there was no difference between samples taken near the top of the Cutler formation and at the bottom of the hole. Also there was no appreciable difference in hardness in drilling near the bottom of the hole and higher in the section.

The curves in Fig. 3 show a comparison of velocities obtained in the well compared with normal Permian velocities.

Curve A is extrapolated from the normal curve for Permian sands and shales, as presented by Dr. Weatherby and Dr. Faust.[4]

Curve B is the Permian section of the same curve as was shown in Fig. 2. The lower part of the curve shows about 55% increase over normal velocity for sediments of the same age and depth.

EXPLANATION OF CONDITIONS

The most noticeable abnormality in the physical properties of the Mancos shale is its unusual hardness as revealed both in samples from wells in the area and in its drillability with hand augers. It is believed that the anomalous velocities in this formation are related to the abnormal lithology and unusual rigidity of the shale. A similar relationship for other formations is indicated.

The unusual rigidity of the shale is believed to be due to some form of alteration or incipient metamorphism after deposition, rather than to any original property of the sediments. Whether such changes as have occurred are due to heat, to pressure either from deep burial or earth movements, or to some cementation process, has not yet been fully investigated. John H. Wilson, in a previous paper has suggested that the abnormal hardness in well samples is due to pressure metamorphism.[5]

CONCLUSIONS AND APPLICATIONS

The area discussed appears to be an area of abnormal velocities, both near the surface and in some of the wells. This condition is believed to be related to an observed hardening of the formations and to be due to some form of alteration or incipient metamorphism since deposition.

The conditions appear to affect adversely the quality of reflection records, probably due to the gradual increase in velocity.

The method of interpretation of refraction data, by which it is assumed that granite, limestone, salt, etc., have characteristic velocities, cannot be safely utilized in such an area, for a sand and shale

[4] Influence of Geological Factors on Longitudinal Seismic Velocities" by B. B. Weatherby and L. Y. Faust, GEOPHYSICS, Vol. 5, March 1935.

[5] Lithologic Character of Shale as an Index of Metamorphism" by John H. Wilson. Bulletin American Association of Petroleum Geologists, Vol. 10, No. 6, pp. 625, June 1926.

section may have velocities normally characteristic of much more consolidated or crystalline material.

The writers do not have sufficient information at hand to state whether or not the suggested alteration or incipient metamorphism has so affected the sediments, associated with such marked increases in velocity, either in manner or degree so as to preclude the possibility of finding oil and gas in commercial quantities. However, the results in this and other Rocky Mountain areas, where some preliminary studies have been made, suggest the possibility, as yet not fully investigated, that abnormal velocities may in some areas be an indication of metamorphism. Where the nature of the metamorphism is understood, changes in velocities in a uniform formation may be related to, and indicative of the degree of metamorphism to which the sediments have been subjected. Under favorable conditions, the seismologist may in the future not only define the structure, but also determine if metamorphism has progressed to a stage unfavorable to the existence of oil and gas.

REVIEWS OF RECENT PUBLICATIONS

The Van Oilfield, Van Zandt County, Texas. By R. A. Liddle. University of Texas Bull. No. 3601 (dated 1 Jan. 1936) January 1937, 79 pp. 27 plates.

An interesting series of geophysical maps, seismic, torsion balance and magnetometer, are presented together with maps based on the results of the extensive subsequent drilling. Van is a rich oilfield on a very deep salt dome, the presence of whose salt core is known only from the torsion balance data. Attention was first called to the Van prospect by erratic dips, surface faulting, abnormal drainage, and topography. A refraction seismic survey indicated the presence of a dome and gave a good outline of it. Many seemingly unexplainable irregularities in the seismic data now are known to be the effect of the complicated faulting of the dome. The presence of the salt is indicated by a broad gravity minimum which contrasts with the shallower minimum and sharp maximum of the shallow Grand Saline salt dome not far to the northwest. The position of the Van dome and oilfield is indicated with good accuracy by the residual minimum after the elimination of a regional anomaly. A faint magnetic minimum seems associated with the dome. The details of the structure were worked out be detailed surface mapping and by an east-west and a north-south series of core-holes. This report presents one of the most detailed series of structure-contour maps which have been published on any structure.

DONALD C. BARTON

The Interrelation of Geology and Geophysics. By O. L. Brace, American Association of Petroleum Geologists, Bulletin, February, No. 2, Vol. 21, 1937, pp. 197–211.

This paper is essentially an argument for the time worn viewpoint wherein the geologist is pictured as omniscient and benign, bearing with his errant brethren, the geophysicists, and waiting for his recognition and repentance after which the geologist, like Moses, will lead the prodigal but forgiven geophysicist to the promised land to be again the "tool of the geologist," whereat everything, once more, is hunky-dory.

The theses is based upon the "common geological knowledge that throughout most of the petroliferous provinces of the country, folds and faults that are the product of regional crusted adjustments, tend to arrange themselves, in their relation to one another, into more or less regular structural patterns.—The recognition of the influence of such regional effects upon structural arrangement is important, especially in its bearing upon structural interpretation."

From a consideration of "Regional Structural Aspects," as typified above, the next step is to "Local Structural Aspects," where another generalization is made, that "Just as the structures, that are the product of regional movement, ordinarily occur in a relationship to one another that is generally predictable, so do individual structures assume forms that are characteristic of the local phase of the regional forces that have produced them." Thus, "the traps formed as a part of the Balcones system are essentially of the same type, even though they may differ rather radically in detail.—In the Permian Basin area of West Texas and New Mexico, traps that serve to accumulate oil and gas will fall within one of two or three distinct types."

With regard to the Gulf Coast, in which both Mr. Brace and the reviewer meet on a ground of common interest, the statement is made that "although it is probable that the pattern of occurrence of coastal domes is a haphazard one, individual domes have

a sufficient similarity one to another, that they may be placed in a rather restricted group of types," as follows (verbiage from the text, arrangement by the reviewer).

A. Piercement Domes ("occupants of one class, in that all more or less of same form, individual variations from type are abut secondary to the preponderant qualities that characterize them")

Likenesses	*Differences*
More or less circular symmetry	Size
	Degree of dip of flanks
	Presence or absence of overhang

B. Deep Seated Domes ("Increase in individualism—members somewhat orthodox in structural form")

Likenesses	*Differences*
Circular in shape	Fault patterns
All of same orthodox type	a. Simple faults
	b. Upthrow faults
Little or great distortion	c. Downthrow faults
Central graben and additional	Intensity of fault
a. Radial faults	Major central grabens-Anticline
b. Radial grabens	Minor central grabens-Dome

C. "Each individual member constitutes an important problem."

Likenesses	*Differences*
Uplifted area incorporates few of the structural features—recognized in connection with salt domes.	Minor closure on downthrow side of fault
	Structural noses—up dip closure by lensing or faulting, area of closure formed by series of faults, blocks barren or productive without exact relationship to structure.

(Apparently the likenesses of this class are the unlikenesses of the individuals—i.e., they are alike in their unlikeness.)

Later, the statements are made, "A dip reading taken on a unit of strata exposed at the surface differs in no important degree from a slope sketched on a seismic record or a section of stratum horizons indicated by correlation of two adjacent well logs.—It is true that the (reflection seismograph) results are more than ordinarily significant because they have been obtained in areas where other sources of structural information have failed but, from a purely technical viewpoint, there is nothing new in type nor is there release from the limitations that characteristically surround such data."

With these statements, the reviewer has no dispute! There is no essential conflict, as yet, between the geologist and the geophysicist, as to who takes the data. Both agree that the data should be taken by the technician best qualified to do so. The geophysicist has so far left to the geologist the securing of data pertinent to surface dips, well log correlation, and areal geology. The geologist has left the actual manipulation and design of the torsion balance, the gravity meter, and the seismograph to the geophysicists.

The difference between the two viewpoints has come in:

1. The direction of the work.
2. The interpretation of the data.

In regard to the first difference, the direction of the work, I agree with Weatherby* that this job is best left to the technical man best fitted for command. Napoleon was originally an artilleryman, Allenby a cavalryman, Leonard Wood a surgeon, Caesar a politician, and Grant an engineer. In the face of these examples, it would be most unreasonable to regulate so that each commanding general should conform to a preconceived type, or have fulfilled a routine course of education. The outstanding strategists of the oil industry in the past were neither geologists nor geophysicists, and while it is probable, it is not necessarily certain that the exploration strategists of the future will be drawn from the ranks of either the geologists or the geophysicists.

With regard to the second difference, the real point at issue comes to the fore. Mr. Brace says, on page 210, that "a structural problem can be solved only by first resolving it into its component parts." The process of building these parts back into "a picture that is not in conflict with recognized controlling structural elements is a step that is accomplished with no material change in the objective nor in the *character* of the *end product*, regardless of whether the recording process has been effected by surface, subsurface, or geophysical means." If for *character* the reviewer is permitted to substitute *quality*, then the die is cast. It is just this building of an *acceptable* structural picture, based upon the asumption that there is nothing new either under the sun or in any given province, that invariably results in the orthodox geologist exposing his weak side, or even rear, to attack. The interpretation of structure based upon preconceived ideas of type is, of course, a shining example of orthodoxy, and, as shown before, can be carried to such an extreme that things are recognized as being alike in their unlikeness (See above).

From the following excerpts, I am inclined to believe that this tendency towards orthodoxy existed before the days of geophysics. I quote from Dr. Lahee's article on "The Mexia and Tehuacana Fault Zones," pages 304–388, "Structures of Typical American Oil Fields," Vol. 1, relative to the discovery of oil at the Mexia Field.

p. 309 "At this depth, with the advice of F. Julius Fohs, this well was taken over by the late A. E. Humphreys. . . . By August 1921, there were ten or twelve producing wells. . . . However, not until after the drilling of a dozen or more wells to the Woodbine sand did geologists begin to realize the importance of the faulting associated with the structure. As a matter of fact, a correct understanding of the nature of this faulting was probably not reached until after the principle campaign of lease trading had been finished."

p. 312 "The discovery well of the Woodbine pay (Conroe Field) was Meador No. 1 . . . completed . . . in October 1921. . . . It is an interesting fact that this location was selected near the crest of a supposed essentially unbroken surface anticline, for as in the case of Mexia, early geological work failed to reveal the importance of the major fault."

p. 309 "In 1914 Alexander Deussen had written as follows—'A fault of small throw crosses the country in a northeast-southeast direction.—It is probable that the gas

* "Organization of an Effective Exploration Department," B. B. Weatherby, Geophysics, Vol. 1, No. 2, June 1936. pp. 179–188.

in the Mexia district is found in these directions and locally marked sands on the east side of the fault'."

From these quotations of Dr. Lahee's, it can be inferred that as far back as 1921 and 1922, geological interpretation suffered from orthodoxy, and general *acceptance* of the true structural conditions at Mexia and Powell was delayed well into 1922, although an answer certainly not far from correct had been postulated in 1914. A similar battle against orthodoxy took place when the reflection seismograph first delineated the characteristics of deep seated domes, in 1930, in the Gulf Coast.

While Mr. Brace may cavil at the geophysicist's nonchalant assumption of credit for recent discovery, the reviewer might also comment upon the geologist's nonchalant assumption of credit for the recognition of structural types of sediments over the deep seated domes. In 1932 the reviewer interpreted the reflection data at Charenton showing that the Chetemeches #1 well was located on a local high in a low formed by two roughly parallel faults. Although that interpretation was inspected by two competent Gulf Coast geologists, and by other geologists recognized as competent in East Texas, the "graben" and its possible effect on localizing production was not recognized at that time. Later the "graben generalization" became popular, after it, too, was acceptable.

The difference between the two attitudes is primarily that the orthodox geologist attempts to fit the data to a preconceived picture, while the geophysicist attempts to fit a picture to data as recorded. Of the two methods, the latter is by far the more scientific, and as long as that situation remains essentially unchanged, the geophysicists will not, and should not, yield to the geologist in interpretation. The geologist must learn to treat scientific data in a scientific fashion.

The geologist's method of attack, as too often displayed, consists of first getting all the well data in a given area, in itself good practise, and then accepting only such of the geophysical data as conform. Properly, of course, all the available data should be evaluated as to reliability. The acceptance of the reflection technique in Oklahoma, in 1927, was materially delayed because the reflection datums failed to check subsea well datums by as much as three to six hundred feet. Finally, a method was developed to check on the subsea elevations of wells from the surface by lowering a geophone to the bottom of the hole, and locating that point acoustically (U. S. Patent No. 1,811,648, June 23, 1931, issued to E. E. Rosaire), and the discrepancies were found, quite logically, to be due to crooked holes. But, here again, acceptance of the new exploration technique was delayed because of failure to agree with the old, a perfect example of orthodoxy at its worst.

Mr. Brace also says that "there are indications, in areas subjected to thorough prospecting, that the days of easy, successful accomplishment for geophysical methods are passing, and this change is, in part, being effected by the gradual elimination of old prospects that have resulted from decades of comprehensive geological study." Nostalgia for the return of the horse and buggy days! Some of us remember riding the refraction seismograph to its ignominious end in 1930 and 1931, and before that W. F. Henninger said as follows (pp. 776, Geology of Salt Dome Oil Fields, 1926). "That it becomes increasingly difficult to find additional domes is apparent when we consider that of the forty known domes in the Gulf Coast, thirty-seven were found from 1901 to 1913. Of the other three, two were found in 1917 and one in 1922. Since the discovery in 1917 of the Hager-Martin dome (Sec. 28) . . . approximately 675 wildcat wells have been drilled in search of new domes on the coast, involving an expense estimated at $20,000,000, exclusive of the cost of leases and overhead expenses. Yet only one new

dome has been found during this period and it has not yet proved profitable commercially as a source of oil." Would a "guidance that is based upon a more intensive application of geological principles" (Brace) have helped the industry, in 1923, or in 1930, to find more salt domes in the Gulf Coast? The need in 1923, in 1930, was, and is again, in 1937, for the development and introduction of methods with finding powers still higher than yet available. In each case the problem was and is tactical, not strategical.

Rather than the omniscient and benign picture of the geologist mentioned at the start of the discussion, it is more probable that the geologist, first of the scientifically trained men to enter the oil industry, had to battle his way into the sun against the last ditch opposition of those practical men who clung to their version of orthodoxy. Now that geology and geophysics take their place in the broader aspect of the science of exploration for our dwindling and less obvious petroleum resources, there will be some geologists, who in their fears, will cling to their version of orthodoxy, and prate of "geophysics as a tool for the geologist." But, suppose, as may well be the case, that these remaining, less obvious, and as yet undiscovered oil fields are the ones which do not conform to type? Then, what price orthodoxy?

E. E. ROSAIRE

"Principles and Practical Results of Geophysics," The Petroleum Times: Vol. (new series) 36, No. 916, 1 August 1936. Pages i to xlviii and 141, 143, and 151; 22 Half tone Pictures of Work in the Field; 28 Maps and Diagrams.

This is a most interesting short account of geophysical prospecting; its history, principle successes and world use. The authorship is anonymous but seemingly must lie close to the Schlumberger organization. Both educated layman and professional geophysicist will read it with interest. It comprises a short history of geophysical prospecting; extracts from a lecture by Conrad Schlumberger on the "Present Position as to the Geophysical Methods," exploration of drillholes, a brief statement of the technique of magnetic, gravimetric and resistivity methods, application of the resistivity method in the Alsatian potash basin, and in the Baker district, seismic method, world-wide use and success of the geophysical methods of prospecting and the more important geophysical companies of the world.

A point of interest in the statistics is the great importance the U.S.S.R. places on surface electrical prospecting, 23 surface electrical parties against 5 seismic parties; for Roumania 2 surface electrical parties are listed against 1 each for the seismic and gravimetric methods, although for the world as a whole, 35 surface electrical parties are listed against 110 seismic (figures much too low for the United States) and 74 gravimetric.

The survey of the world use of geophysical prospecting and the maps showing the areas covered in North America, Roumania, North Africa, and the U.S.S.R. are particularly interesting.

DONALD C. BARTON

PERSONAL ITEMS

Dr. E. E. Rosaire has resigned as president of the Independent Exploration Company and has organized Subterrex, a new company engaging in Geophysics and Geochemistry.

Mr. Stuart Sherar has resigned as Head of the Geophysical Division of the Carter Oil Company of Tulsa and is planning to enter the lease and royalty business. Dr. A. B. Bryan will take over the duties of Mr. Sherar.

Dr. L. W. Blau has been promoted to head Geophysics and Production Research of the Humble Oil & Refining Company, with Dr. W. M. Rust, Jr. as Director of Geophysics Research Division and T. V. Moore as Director of Production Research Division.

Dr. F. M. Kannenstine has organized the Kannenstine Laboratories for the purpose of building geophysical instruments.

THE SOCIETY ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following candidates for membership in the Society. This publication does not constitute an election, but places the name before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Secretary. (Names of sponsors are placed beneath the name of each nominee.)

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C. G. Morgan, 709 Kennedy Bldg., Tulsa, Okla.
*E. L. Mount, Geophysical Div. Continental Oil Co. Ponca City, Okla.
W. D. Mounce, Box 2180, Houston, Tex.
D. C. Muzzey, Jr., Shell Petroleum Co., Houston, Tex.
M. Mott-Smith, 2011 Esperson Bldg., Houston, Tex.

J. N. Nahas, 1210 Ashley Ave., Beaumont, Tex.
C. C. Nash, Jr., 256 Humble Bldg., Houston, Tex.
W. D. Neff, 4048 Travis St., Dallas, Tex.
J. H. Neidert, Seismograph Party #1, Lago Petroleum Co. Maricaibo, Venezuela, S.A.
L. L. Nettleton, Box 2038, Pittsburgh, Pa.
F. J. G. Neumann, 2600 Esperson Bldg., Houston, Tex.
L. J. Neuman, 1520 Hawthorne, Houston, Tex.
C. J. Newby, Box 2180, Houston, Tex.
D. N. Newell, 2011 Esperson Bldg., Houston, Tex.
W. W. Newton, 902 Tower Petroleum Bldg., Dallas, Tex.
W. P. Noser, 256 Humble Bldg., Houston, Tex.

D. O'Brien, Box 2180, Houston, Tex.
D. S. Oddone, Rua Santa Amelia 35, (Mattoso) Rio de Janiero, Brazil, S.A.
T. A. Ogg, 503 W. 19th St., Houston, Tex.
W. J. Osterhoudt, Drawer 2100, Houston, Tex.

*E. J. Owen, 2011 Esperson Bldg., Houston, Tex.
J. E. Owen, Box 2040, Tulsa, Okla.

R. L. Palmer, McCollum Exploration Co., Esperson Bldg., Houston, Tex.
*L. A. Parker, 2011 Esperson Bldg., Houston, Tex.
H. S. Patrick, Box 2180, Houston, Tex.
H. B. Peacock, 825 Esperson Bldg., Houston, Tex.
F. Perkinson, Cordilleria Pet. Corp., Apartado 1706, Caracas, Venezuela, S.A.
D. E. Petty, Box 1477, San Antonio, Tex.
O. S. Petty, Box 1477, San Antonio, Tex.
*S. C. Peters, Box 2180, Houston, Tex.
S. Pirson, Petroleum Engineering Dept. Pennsylvania State College, State College, Pa.
C. V. A. Pittman, 1311 Republic Bank Bldg., Dallas, Tex.
L. Poindexter, 1311 Republic Bank Bldg., Dallas, Tex.
J. C. Pollard, Magnolia Petroleum Co., Houston, Tex.
T. T. Pope, 2011 Esperson Bldg., Houston, Tex.
J. A. Pranglin, 2011 Esperson Bldg., Houston, Tex.
H. R. Prescott, 428 S. Pine St., Ponca City, Okla.

*G. H. Rabson, 301 Eden St., Plaquemine, La.
*K. Ransone, 2011 Esperson Bldg., Houston, Tex.
W. R. Ransone, 1311 Republic Bank Bldg., Dallas, Tex.
R. H. Ray, 2315 Gulf Bldg., Houston, Tex.
*E. C. Reagor, 1311 Republic Bank Bldg., Dallas, Tex.
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C. E. Reel, 164 N. Hill St., Pasadena, Calif.
D. S. Renner, 1621 Summit St., Columbus, Ohio.
F. F. Reynolds, 2424 Gulf Bldg., Houston, Tex.
F. Rieber, 1007 Broxton Ave., Los Angeles, Calif.
M. Riess, Box 801, Tulsa, Okla.
P. A. Rodgers, 2011 Esperson Bldg., Houston, Tex.
*M. Romberg, 256 Humble Bldg., Houston, Tex.
E. E. Rosaire, 2011 Esperson Bldg., Houston, Tex.
*F. C. Rosaire, 2011 Esperson Bldg., Houston, Tex.
C. G. Rosaire, 2011 Esperson Bldg., Houston, Tex.
H. W. Rose, Sun Oil Co., Beaumont, Tex.
C. M. Ross, Box 2040, Tulsa, Okla.
W. M. Rust, Jr., 806 Waugh Drive, Houston, Tex.
C. A. Russell, 1810 Petroleum Bldg., Houston, Tex.
F. R. Ryan, 1806 Sterling Bldg., Houston, Tex.

H. Salvatori, 606 Petroleum Securities Bldg., Los Angeles, Calif.
G. H. Samuels, Box 398, Plaquemine, La.
I. Sandidge, Jr., Box 1112, Ft. Worth, Tex.
W. G. Saville, 1414 Shell Bldg., Houston, Tex.
R. Saibara, 2011 Esperson Bldg., Houston, Tex.
J. H. Sawyer, Shell Petroleum Co., Houston, Tex.
D. Scharf, 2011 Esperson Bldg., Houston, Tex.
L. A. Scholl, Box 2332, Houston, Tex.
*J. E. Schneider, Box 346, Lake Arthur, La.
J. P. Schumacher, 1406 Shell Bldg., Houston, Tex.
A. T. Schwennesen, 1011 Sterling Bldg., Houston, Tex.
A. L. Selig, 3350 Wichita, Houston, Tex.
*J. R. Sexton, 1311 Republic Bank Bldg., Dallas, Tex.
*W. A. Seyffert, 816 Joplin National Bank Bldg., Joplin, Mo.
N. R. Shade, 3747 Effingham Pl., Los Angeles, Calif.
M. D. Shappell, 14731 Valley Heart Dr., Van Nuys, Calif.
*C. A. Shapard, 2011 Esperson Bldg., Houston, Tex.
J. A. Sharpe, 1011 S. Flower St., Los Angeles, Calif.
E. S. Sherar, c/o N.K.P.M. Soengei Gerong, Palembang, N.E.I.

S. Sherar, Box 801, Tulsa, Okla.
H. F. Shore, 2011 Esperson Bldg., Houston, Tex.
W. B. Sibley, 1117 S. Detroit, Tulsa, Okla.
M. M. Slotnick, Box 2180, Houston, Tex.
A. L. Smith, 2011 Esperson Bldg., Houston, Tex.
C. C. Smith, Box 2038, Pittsburgh, Pa.
G. H. Smith, Eastern Lab. E. I. du Pont de Nemours & Co., Gibbstown, N.J.
*L. J. Smith, Box 476, Centralia, Ill.
G. B. Somers, 721 Browder St., Dallas, Tex.
G. W. Somers, So. Texas Geophysical Corp. 20th Floor Sterling Bldg., Houston, Tex.
J. L. Soske, 199 S. Fair Oaks Ave., Pasadena, Calif.
J. S. Spencer, Box 2180, Houston, Tex.
M. G. Spencer, 1311 Republic Bank Bldg., Dallas, Tex.
A. N. Stanton, Geophysical Petroleum Surveys, Dallas, Tex.
L. Statham, 1706 Waugh Drive, Houston, Tex.
N. H. Stearn, 1226 Olive St., St. Louis, Mo.
W. E. Steele, 2011 Esperson Bldg., Houston, Tex.
M. E. Stiles, 2011 Esperson Bldg., Houston, Tex.
*G. B. Stone, 2011 Esperson Bldg., Houston, Tex.
S. C. Stoneham, 1311 Republic Bank Bldg., Dallas, Tex.
A. E Storm, 1311 Republic Bank Bldg., Dallas, Tex.
H. W. Straley III, University of North Carolina, Chappel Hill, N.C.
*G. Stubbe, American Askania Corp., M. & M. Bldg., Houston, Tex.
E. Stulken, 1311 Republic Bank Bldg., Dallas, Tex.
*R. L. Suggs, 256 Humble Bldg., Houston, Tex.
O. F. Sundt, 1312 Esperson Bldg., Houston, Tex.
E. Sweet, 1426 Esperson Bldg., Houston, Tex.

J. Taylor, 1404 Shell Bldg., Houston, Tex.
W. H. Taylor, Box 1477, San Antonio, Tex.
E. Thomas, 1311 Republic Bank Bldg., Dallas, Tex.
J. W. Thomas, 1311 Republic Bank Bldg., Dallas, Tex.
R. R. Thompson, 256 Humble Bldg., Houston, Tex.
H. R. Thornburgh, Shell Petroleum Corp., Houston, Tex.
A. Tidemann, B.P.M. Bandjermasin, Borneo, D.E.I.
*F. A. Tompkins, 77 Lake Crest Rd., Rochester, N.Y.
E. J. Toomey, 1311 Republic Bank Bldg., Dallas, Tex.
B. H. Treybig Jr., Box 2332, Houston, Tex.
*A. C. Trigg, 256 Humble Bldg., Houston, Tex.

O. M. Urbom, 2011 Esperson Bldg., Houston, Tex.
*R. Urick, Shell Petroleum Corp., Shell Bldg., Houston, Tex.

O. F. Van Beveren, 4361 Colfax Ave., North Hollywood, Calif.
S. Van Croy, 2212 Esperson Bldg., Houston, Tex.
A. Van Weelden, c/o Bat. Petr. Mpy., Carel v. Bylandtlaan 30, The Hague, Holland.
J. Vernon, Box 2040, Tulsa, Okla

*R. B. Wagner, 9135 Larke Ellen Circle, Los Angeles, Calif.
G. E. Wagoner, Box 801, Tulsa, Okla.
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*T. E. Wall, 1426 Esperson Bldg., Houston, Tex.
G. C. Walton, Box 801, Tulsa, Okla.
D. Wantland, Colorado School of Mines, Golden, Colo.
T. R. Warrick, Standard Oil of Venezuela, Caripito, Venezuela, S.A.
H. W. Washburn, 714 W. 10th St., Los Angeles, Calif.
G. R. Watson, Box 2038, Pittsburgh, Pa.
J. S. Watt, 266 Humble Bldg., Houston, Tex.
B. B. Weatherby, Box 2040, Tulsa, Okla.

*S. P. Weatherby, 2011 Esperson Bldg., Houston, Tex.
P. Weaver, Box 2100, Houston, Tex.
J. F. Weinzeril, Riverside, Tex.
O. Weiss, 19 Whitehall Court, Killarney, Johannesburg, Union of S. Africa.
S. S. West, 2011 Esperson Bldg., Houston, Tex.
G. H. Westby, 709 Kennedy Bldg., Tulsa, Okla.
G. E. White, 256 Humble Bldg., Houston, Tex.
*K. D. White, Bulevardul Tache Ionescu 1, Bucharest, Roumania.
A. K. Wilhelm, Empire Oil and Refining Co., Bartlesville, Okla.
S. H. Williston, 905 Public Service Bldg., Portland, Ore.
C. H. Wilson, 8560 Olimpic Blvd., Los Angeles, Calif.
J. H. Wilson, 610 Midland Savings Bldg., Denver, Colo.
*E. D. Williams, Box 2040, Tulsa, Okla.
B. O. Winkler, Tropical Oil Co., Barranca Bermeja, Colombia, S.A.
*V. G. Winston, 524 Republic Bank Bldg., Dallas, Tex.
A. Wolf, Box 2332, Houston, Tex.
E. M. Wolters, Box 2180, Houston, Tex.
J. P. Woods, Shell Petroleum Corp., Houston, Tex.
*R. V. Woodward, 208 Spring St., Medicine Lodge, Kan.
R. D. Wyckoff, 1215 Barkdull St., Houston, Tex.

*F. L. Yeates, 2011 Esperson Bldg., Houston, Tex.

S. Zimerman, Box 238, Effingham, Ill.
C. C. Zimmerman, The Texas Company, Houston, Tex.
*B. B. Zavoico, Gulf Bldg., Houston, Tex.
N. N. Zirbel, 2011 Esperson Bldg., Houston, Tex.

Honorary Members

E. L. DeGolyer, Esperson Bldg., Houston, Tex.
L. Mintrop, University of Breslau, Breslau, Germany.
W. E. Pratt, Box 2180, Houston, Tex.
L. P. Garrett, Box 2100, Houston, Tex.

MINUTES OF THE BUSINESS MEETING OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS AT THEIR SECOND ANNUAL MID-YEAR MEETING, HELD AT HOUSTON, TEXAS, NOVEMBER 20–21, 1936

The regular business meeting of the Society of Exploration Geophysicists at the second mid-year meeting was held at 9:00 o'clock in the morning in Room A, Mezzanine Floor of the Rice Hotel, Houston, Texas on November 20th, 1936.

President L. W. Blau presided at the meeting.

On motion duly made, seconded and carried, the reading of the minutes of the previous business meeting was dispensed with and the minutes as published in "GEOPHYSICS" were approved.

The Secretary-Treasurer presented his report showing the total number and geographic distribution of members, the income and expense of the Society for 1936 up to and including October 31st, 1936, and the balance sheet of the Society up to the same date.

The report of the Committee on Safety was read by Mr. A. C. Burnett.

A report on the status of the Society as a technical division of the American

Association of Petroleum Geologists was read and discussed. On motion duly made, seconded and carried the action taken by the Executive Committee toward resignation of the Society as a technical division of the American Association of Petroleum Geologists and the simultaneous application for the status of an affiliated Society was approved.

A committee consisting of Dr. Barton, Dr. Slotnick and Mr. Harkins appointed by the President to canvass the results of the ballots on the proposed constitutional amendments reported that all of the proposed amendments had carried by the following votes:

Amendment No.	*For*	*Against*
1	109	58
2	142	24
3	144	22
4	160	6
5	142	13
6	151	6
7	147	15
8	157	4

Upon motion duly made, seconded and carried the meeting adjourned. Some 275 members and guests registered during the meeting.

JOHN H. WILSON,
Secretary-Treasurer

SECOND MID-YEAR MEETING

OF THE

SOCIETY OF EXPLORATION GEOPHYSICISTS

Nov. 20th–21st, 1936

Headquarters and Meetings, Rice Hotel, Houston, Texas.

FRIDAY, NOV. 20TH

7:45	Registration, Mezzanine floor
9:00–10:00	Business Meeting—Room A—Mezzanine floor
10:00–12:00	Technical Session of the Society in Room A, Mezzanine floor
12:00– 1:00	Joint Luncheon of the S. P. G. and the Houston Geological Society—Ball Room, Mezzanine floor
2:00– 5:00	Technical Session of the Society in Room A, Mezzanine floor
6:30	Stag dinner—Banquet Room 1—Rice Hotel

SATURDAY, NOV. 21ST

9:00–12:00	Technical Session of the Society—Room A, Mezzanine floor
2:30	Rice-T. C. U. Football Game, Rice Stadium
10:00	Houston Geological Society Dance—Houston Club

FRIDAY, NOV. 20TH

7:45 Registration—Mezzanine floor

9:00–10:00 Business Meeting—Room A
Chairman, L. W. Blau

10:00–12:00 Technical Session—Room A
Chairman, T. I. Harkins

Papers:

1. Exploration of the Reflection Seismograph in the Gulf Coast of Texas and Louisiana.....E. E. Rosaire
2. Gravitational Survey with the Gravity Meter...L. M. Mott-Smith
3. The Effect of Moisture on the D. C. Resistivity of Oil Sands.....J. J. Jakosky and R. H. Hoppe
4. Abnormal Velocities in Sedimentary Beds in Wester Utah.....A. L. Smith and J. H. Wilson

2:00– 5:00 Technical Session—Room A
Chairman, G. H. Westby

Papers:

1. A Research Library in the Geophysical Field...James B. Macelwane
2. Some Gulf Coast Velocity Curves.....C. M. Boos
3. Geologic Discussion of the Gulf Coast.....F. W. Rolshausen
4. Psychology and Geophysical Exploration in the Gulf Coast.....E. E. Rosaire and K. Ransone
5. Complex Reflection Patterns and their Geologic Sources.....Frank Rieber
6. Keeping Cost Records on Insurance.....A. C. Burnett
7. Recent Developments in Explosives for Seismograph Exploration.....W. Farren, Guy Roland and Harold White

7:30 Stag Dinner—Banquet Room 1—Toastmaster, L. W. Blau

17. Re-organization of an Inoffensive Exploitation Department.....By N. G. Weathering and Geo. L. O'Gist
18. Election Reports, Literary Indigestion Report....By T. B. Alance

SATURDAY, NOV. 21ST

9:00–12:00 Technical Session—Room A
Chairman, John H. Wilson

Papers:

1. Let the Physicists Change Your Oil.....Paul D. Foote
2. Electro-Chemical Exploration and Correlation of Cased Bore-Holes.....M. C. Bowsky
3. Field Technique of the Magnetometer and its Uses in Locating Serpentine Plugs.....Paul D. Crawford
4. Notes on Dip Shooting.....Sylvan Pirson
5. Developments of Essential Characteristics of Electric Blasting Caps for Seismograph Prospecting.....W. Farren, Guy Roland and Harold White

Board of Directors
Society of Exploration Geophysicists
Denver, Colorado

GENTLEMEN:

In accordance with your direction, we have audited the financial records of the Society of Exploration Geophysicists for the year ended December 31, 1936. The results of our audit are presented in this report, which includes: (1) text of comments and explanatory detail; (2) statement of income and expense for the year ended December 31, 1936; (3) statement of financial condition at December 31, 1936; (4) schedules supplementing the foregoing statements.

COMMENTS RESPECTING STATEMENT OF INCOME AND EXPENSE

The amount of excess of income over expenses and the factors entering into the determination of this amount are presented in exhibit A.

Income and expense items, as shown on this exhibit, are taken from your books.

The disbursements covering all expenses were supported by vouchers with statements from the parties receiving payment.

COMMENTS RESPECTING FINANCIAL CONDITION

The financial condition at December 31, 1936, is presented in detail in exhibit B. The following comments are made with respect to certain items on exhibit B.

CASH ON DEPOSIT—$2,110.05:

The details of the cash on deposit were as follows:

International Trust Company, Denver, Colo.	$1,802.50
National Bank of Tulsa, Okla.	307.55
	$2,110.05

Direct verification of the above amount was received from the depositories.

ACCOUNTS RECEIVABLE—$827.98:

The accounts receivable are taken from your records and we made no direct verification of the same.

SURPLUS—$2,134.00:

The surplus as of January 1, 1936, after adjustments made during 1936 affecting 1935 and prior years' transactions amounted to $1,409.32. The excess of income over expenses for the year 1936 amounted to $724.68.

INDEX TO STATEMENTS

Details as to income and expense and financial condition are presented in the statements contained herein, as listed in the following tabulation:

Exhibit A—Statement of income and expense, year ended December 31, 1936
Exhibit B—Statement of financial condition at December 31, 1936
Schedule B-1—Accounts receivable—dues, January 1, 1936 to December 31, 1936

Schedule B-2—Accounts receivable—advertising at December 31, 1936
Schedule B-3—Accounts receivable—subscriptions, at December 31, 1936
Schedule B-4—Accounts receivable—reprints at December 31, 1936
Schedule B-5—Accounts receivable—back numbers at December 31, 1936

Respectfully submitted,
LINCK AND ALSFASSER

SOCIETY OF EXPLORATION GEOPHYSICISTS

STATEMENT OF INCOME AND EXPENSE
YEAR ENDED DECEMBER 31, 1936

Income:		
Dues income	$2,025.00	
Dues income—reinstatements	45.00	
Subscription income	594.90	
Sale of back numbers	346.77	
Advertising income	1,662.00	
Sale of reprints	271.32	
Interest earnings	7.55	
		$4,952.54
Expense:		
Auditing expense	15.00	
Bond premium expense	10.00	
Express and freight	70.69	
Miscellaneous expense	20.08	
Postage	148.63	
Publication expense	2,651.43	
Refunds—publications	14.00	
Reprint expense	363.01	
Stationery and office supplies	302.02	
Stenographic and clerical service	486.80	
Telephone and telegraph	47.90	
Traveling expense	98.30	
		4,227.86
Excess of Income over Expenses		$ 724.68

SOCIETY OF EXPLORATION GEOPHYSICISTS

STATEMENT OF FINANCIAL CONDITION
AT DECEMBER 31, 1936

Assets:			
Cash on deposit		$2,110.05	
Accounts receivable—dues—schedule B-1	$ 60.00		
Accounts receivable—advertising—schedule B-2	625.00		
Accounts receivable—subscriptions—schedule B-3	89.75		
Accounts receivable—reprints—schedule B-4	13.32		
Accounts receivable—back numbers—schedule B-5	39.91		
		827.98	
			$2,938.03
Liabilities:			
Prepaid dues—schedule B-1		15.00	
Accounts payable		789.03	
			804.03
Excess of Assets over Liabilities			$2,134.00
Represented by:			
Surplus—January 1, 1936—adjusted		1,409.32	
Excess of income over expenses, year ended December 31, 1936—exhibit A		724.68	
			2,134.00

NOTE: Exhibits B-1, B-2, B-3, B-4, and B-5 have been omitted because of their length, but may be inspected at the office of the Secretary-Treasurer.

REPORT OF NOMINATING COMMITTEE

In Accordance with Artical V, Section 2, of the Constitution of the Society of Petroleum Geophysicists, the Nominating Committee has submitted the following ballot to the Secretary-Treasurer for transmittal to the membership.

OFFICIAL BALLOT

FOR THE YEAR MARCH, 1937–MARCH, 1938
FOR THE ELECTION OF OFFICERS FOR THE
SOCIETY OF EXPLORATION GEOPHYSICISTS

FOR PRESIDENT AND VICE-PRESIDENT

VOTE ONCE FOR PRESIDENT (FIRST CHOICE) AND ONCE FOR VICE-PRESIDENT

	FIRST CHOICE (FOR PRESIDENT)	SECOND CHOICE (FOR VICE-PRESIDENT)
E. A. ECKHART	☐	☐
F. M. KANNENSTINE	☐	☐
J. C. KARCHER	☐	☐
E. G. LEONARDON	☐	☐
_____	☐	☐

FOR SECRETARY-TREASURER

VOTE ONCE

W. T. BORN	☐
M. E. STILES	☐
_____	☐

FOR EDITOR

VOTE ONCE

H. SALVATORI	☐
M. M. SLOTNICK	☐
_____	☐

AFTER VOTING, PLACE IN ACCOMPANYING OFFICIAL ENVELOPE, WHICH SHOULD THEN BE SIGNED AND MAILED TO THE

Secretary-Treasurer
JOHN H. WILSON
610 Midland Savings Bldg.
Denver, Colorado

L. W. BLAU, *President*
B. B. WEATHERBY, *Past President*
E. E. ROSAIRE, *Prior Past President*

At the Annual Meeting held in Los Angeles, California, on March 17–20, 1937, the following officers were elected: President, J. C. Karcher; Vice-President, F. M. Kannenstine; Secretary-Treasurer, M. E. Stiles; and Editor, M. M. Slotnick. L. W. Blau is Past-President.

AMENDMENTS TO THE BY-LAWS

The following proposed amendments to the By-Laws of the Society of Exploration Geophysicists have been recommended and their legality approved by the Executive Committee (E.O. 27).

The proposed amendments having been approved by a favorable vote of the Business Committee (E.O. 28), they are hereby certified as amendments to the By-Laws and ordered published in the next regular issue of GEOPHYSICS in accordance with the provisions of the existing By-Laws.

February 5th, 1937

JOHN H. WILSON
Secretary-Treasurer

By-Laws III-A-2

Strike out "subject to the same requirements as for a constitutional amendment and with legal advice" and in second sentence strike out "and with like advice."

By-Laws V-A-1

Change the last sentence to read: "The Business Committee shall meet the day before the annual meeting at which time proposed changes in the constitution and by-laws may be considered, all old and new business shall be discussed, and recommendations may be voted for presentation at the annual meeting."

EXECUTIVE ORDER NO. 24

In accordance with the provisions of Executive Order No. 24, a "CERTIFICATE OF INCORPORATION OF THE SOCIETY OF EXPLORATION GEOPHYSICISTS" was filed with the Secretary of State of Colorado on February 24th, 1937 with E. E. Rosaire, L. W. Blau, and B. B. Weatherby as incorporators and naming John H. Wilson, 610 Midland Savings Building, Denver, Colorado as resident agent.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

Constitution and By-Laws

(As amended to February 5, 1937)

I. NAME

This Association shall be called the "Society of Exploration Geophysicists."

II. OBJECT

The object of this Association is to promote the science of geophysics especially as it applies to exploration.

III. MEMBERSHIP

A—Members

1. Any geophysicist of recognized standing shall be eligible to membership, whether or not he is engaged in petroleum geophysics or in geophysical prospecting.
2. Any physicist, mathematician, geologist, or engineer of recognized standing who is investigating a geophysical problem or problems shall be eligible to membership.
3. Any geologist of recognized standing who is not a geophysicist of recognized

standing, but who is acting as chief, or division chief in charge of geophysical surveying, shall be eligible to membership.

B—Associates

1. Any geophysicist, geologist, engineer, mathematician, or physicist who is a graduate of an institution of recognized scientific standing who is engaged in geophysics and who is not eligible to membership shall be eligible to associate membership.
2. Any person who is not a graduate of an institution of recognized scientific standing and who is not eligible to membership and who has shown ability in a routine phase of geophysical work and who is in a position of responsibility in geophysical surveying shall be eligible to associate membership.
3. Any representative or employee of a firm or corporation engaged in supplying equipment or supplies to the geophysical prospecting industry, provided such individual is the graduate of an institution of recognized scientific standing, or provided otherwise that such individual is qualified by adequate technical experience shall be eligible to associate membership.
4. Associate members shall be known as associates.
5. Associates shall enjoy all the privileges of membership in the Society, save that they shall not hold office, sign applications for membership, or vote; neither shall they have the privilege of advertising their affiliation with the Society in professional cards or professional reports or otherwise.
6. The executive committee may advance to active membership, without the formality of application for such change, those associates who have, subsequent to election fulfilled the requirements for active membership.

C—Election to Membership

1. Every candidate for admission as a member or associate shall submit a formal application on an application form authorized by the Executive Committee, signed by him, and endorsed by not less than three members who are in good standing, stating his training and experience and such other facts as the executive committee shall from time to time prescribe. Provided the Executive Committee, after due consideration, shall judge that the applicant's qualifications meet the requirements of the constitution, they shall cause to be published in an appropriate publication the applicant's name and the names of his sponsors. If, after at least thirty days have elapsed since such publication, no reason is presented why the application should not be admitted, he shall be deemed eligible to membership or to associate membership, as the case may be, and shall be notified of his election. Provided the Executive Committee may accept applicants for either class of membership, who, because of their geographical location or because of their lack of acquaintance with active members of this Society, are unable to secure qualified sponsors, but who otherwise are eligible for membership.

2 An applicant for membership, on being notified of his election in writing, shall pay full membership dues for the current year and on making such payment shall be entitled to receive the regular Society publications for that year. Unless payment of dues is made within thirty (30) days by those living within the continental United States and within ninety (90) days by those living elsewhere, after notice has been mailed of his election, the executive committee

may rescind the election of the applicant. Upon payment of dues, each applicant for membership shall be furnished with a membership card for the current year, and until such written notice and card are received, he shall in no way be considered a member of the Society.

D—Honorary Members

1. The executive committee may from time to time and by unanimous action elect as honorary members persons who have contributed distinguished service to the cause of geophysics. Honorary members shall not be required to pay dues.

E—Code of Ethics

1. Membership of any class shall be contingent upon conformance with the established principles of professional ethics.

IV

A—Resignation—Suspension—Expulsion

1. Any member or associate may resign from the Society at any time. Such resignation shall be in writing and shall be accepted by the executive committee, subject to the payment of all outstanding dues and obligations of the resigning member or associate.
2. Any member or associate who is more than one year delinquent (in arrears) in payment of dues shall be suspended from the Society. Any delinquent or suspended member or associate, at his own option, may request in writing that he be dropped from the Society and such request shall be granted by the executive committee. Any member or associate more than two years in arrears shall be dropped from the Society. The time of payment of delinquent dues for either one year or two years may be extended by a unanimous vote of the executive committee.
3. Any member or associate who resigns or is dropped under the provisions of Sections 1 and 2 of this article ceases to have any rights in the Society and ceases to incur further indebtedness to the Society.
4. Any person who has ceased to be a member or associate under Section 1 or Section 2 of this article may be re-instated by a unanimous vote of the executive committee subject to the payment of any outstanding dues and obligations which were incurred prior to the date when he ceased to be a member or associate of the Society.
5. Any member or associate who, after being granted a hearing by the executive committee, shall be found guilty of a violation of the code of ethics of this Society or shall be found guilty of a violation of the established principles of professional ethics, or shall be found guilty of having made a false or misleading statement in his application for membership in the Society, shall be asked to resign from the Society by a unanimous vote of the executive committee. The decision of the executive committee in all matters pertaining to the interpretation and execution of the provisions of this section shall be final.

V. Officers and their Duties

A—Officers

1. The officers of the Society shall be a President, a Vice-president, a Secretary Treasurer, and an Editor. These, together with the Past President, shall constitute the Executive Committee and managers of the Society.

2. A ticket of nomination for officers and representatives shall be prepared by a Committee on Nominations, which shall consist of the President, and the two qualified Past Presidents in order of precedence. Favorable action of this committee shall be two out of three votes. The ticket decided on by this Committee, as well as any ticket presented in writing and signed by twenty other members in good standing, shall be submitted to the President by December 31st. At least three candidates for president shall be named on the ticket whenever the incumbent vice-president shall be ineligible for re-election. This shall be placed on a ballot and one mailed to each member in good standing on December 31st by the Secretary-Treasurer, not later than January 10th. A blank space shall be left on this ballot for writing in nominations for each place. Before ballots are mailed the President shall secure written acceptance of nomination from each candidate.

   The nominations for President shall be alphabetically arranged, except the retiring Vice-President, who shall automatically occupy first place on the ticket. Each member shall express a first choice for President, and a second choice for another candidate for President. First choice votes shall count double and second choice shall count single. The candidate receiving the highest number of votes so cast and counted shall be elected President, and the candidate receiving the second highest number of votes so cast and so counted shall be elected Vice-President, except where the choice conflicts with Section Three of Article V, in which case the next highest candidate shall be elected Vice-President.

   Each member shall express one choice for Secretary-Treasurer, and one choice for Editor. The candidates securing the highest number of votes so cast and counted shall be elected Secretary-Treasurer and Editor, respectively.

   Such ballots, to be counted as valid, must be received by the Secretary-Treasurer at his official recognized address not less than ten days prior to the Annual Meeting. The ballots shall be mailed to the Secretary-Treasurer in envelopes which shall carry the written signature and the typewritten name of the member. These ballots will be opened and counted by the Nominating Committee immediately before the Annual Meeting. The Secretary-Treasurer, before the ballots are opened, shall approve by initiating only those ballots received from members in good standing at the time the ballots are presented to the Nominating Committee for counting.

   The announcement of the election will be made as the first of the new business considered at the Annual Meeting. A majority vote of said ballots received in accordance with this action, except where otherwise designated, shall be considered as the will of the Society. In the event of a tie, the favoring secret vote of the nominating committee shall decide.

3. No one shall hold the office of President for two consecutive years and no one shall hold any other office for more than two consecutive years except the Editor, who shall not hold office for more than six consecutive years.

B—Duties of Officers

1. The President shall be the presiding officer at all the meetings of the Society, shall take cognizance of the acts of the Society and of its officers, shall appoint such committees as are required for the purposes of the Society, and shall delegate members to represent the Society. He may, at his option, serve on, and may be chairman of, any committee.

2. The Vice-President shall assume the office of president in case of a vacancy from any cause in that office and shall assume the duties of President in case of the absence or disability of the latter. He shall also act as chairman of the Program and Arrangements Committee of the Society, and as the junior delegate of the Society on the Business Committee of the American Association of Petroleum Geologists.
3. The Secretary-Treasurer shall assume the duties of the president in case of the absence of both the President and Vice-President. He shall have charge of the financial affairs of the Society and shall annually submit reports as secretary treasurer covering the fiscal year, which he shall arrange to have published in the next regular issue of the recognized organ of the society. He shall receive all funds of the Society, and, under the direction of the executive committee, shall disburse all funds of the Society. He shall cause an audit to be prepared annually by a public accountant at the expense of the Society. He shall give a bond, and shall cause to be bonded all employees to whom authority may be delegated to handle Society funds. The amount of such bonds shall be set by the executive committee and the expense shall be borne by the Society. The funds of the Society shall be disbursed by check as authorized by the executive committee.
4. The Editor shall be in charge of the editorial business, shall submit an annual report of such business, shall have authority to solicit papers and material for the regular Society publication and for special publications, and may accept or reject material offered for publication. He may appoint associate, regional, and special editors. He shall serve as senior delegate to the Business Committee of the American Association of Petroleum Geologists.
5. In the event of absence, disability or resignation of any member of the Executive Committee, the vacant place in the Committee shall be automatically filled by the next preceding qualified Past-President who shall be known as Prior Past-President.
6. The officers shall assume the duties of their respective offices immediately after the annual meeting following their election.

VI. Executive Committee—Meetings and Duties

A—Executive Committee

1. The Executive Committee shall consist of the President, Past President, Vice-President, Secretary-Treasurer, and Editor.

B—Meetings and Duties

2. The Executive Committee shall meet preceding the annual meeting and at the call of the president may hold meetings when and where thought advisable, to conduct the affairs of the Society. A joint meeting of the outgoing and incoming Executive Committees shall be held immediately after the close of the annual Society business meeting. Members of the Executive Committee may vote by proxy, mail or person on all matters which call for favorable or unanimous action.
3. The Executive Committee shall consider all nominations for membership and pass on the qualifications of the applicants; shall have control and management of the affairs and funds of the Society; shall determine the manner of publica-

tion; and shall designate the place of the annual meeting. They are empowered to establish a business headquarters for the Society, and to employ such persons as are needed to conduct the business of the Society. They are empowered to make investments of both general and special funds of the Society. Trust funds may be created giving to the trustees appointed for such purpose such discretion as to investments as seems desirable to the Executive Committee to accomplish any of its objects and purposes, but no such trust funds shall be created unless they are revocable upon ninety (90) days' notice. Favorable action shall consist of a favoring three out of five votes. Committee members may vote by person, proxy or in writing.

VII

A—Meetings

1. The Society shall hold at least one stated meeting each year, which shall be the annual meeting. This meeting shall be held at a time and place designated by the Executive Committee. At this meeting the proceedings of the preceding meeting shall be read, Society business shall be transacted, scientific papers shall be read and discussed, and results announced of the mail ballot for officers for the ensuing year.

VIII

A—Amendments

1. Amendments to this constitution may be proposed by a resolution of the Executive Committee, by a Constitutional Committee appointed by the President, or in writing by any ten members of the Society. All such resolutions or proposals must be submitted at the annual meeting of the Business Committee of the Society as provided in the by-laws, and only the Business Committee shall make recommendations concerning proposed constitutional changes at the annual Society business meeting. If such recommendations by the Business Committee shall be favorably acted on at the annual Society business meeting, the Secretary-Treasurer shall arrange for a ballot of the membership by mail within thirty (30) days after said annual Society business meeting, and a majority vote of the ballots received within ninety (90) days of their mailing shall be sufficient to amend. The legality of all amendments must be determined by the Executive Committee prior to balloting.

B—Parliamentary Regulations

1. The rules contained in "Roberts Rules of Order, Revised" shall govern the Society in all cases to which they are applicable, and in which they are not inconsistent with the by-laws or the special rules of order of this Society.

BY-LAWS

I

A—Dues

1. The fiscal year of the Society shall correspond with the calendar year.
2. The annual dues of members of the Society shall be five dollars ($5.00). The annual dues of associates for not to exceed six years after election shall be four dollars ($4.00); thereafter, the annual dues of such associates shall be five dollars ($5.00). The annual dues are payable in advance on the first day of each calendar year. A bill shall be mailed to each member and associate before

January first of each year, stating the amount of the annual dues and the penalty and conditions for default in payment. Members or associates who shall fail to pay their annual dues by March fifteenth shall not receive further copies of the regular Society publication, shall not be eligible to vote, nor shall they be privileged to buy Society special publications at prices made to the membership, until such arrears are met.

II

A—Publications

1. The proceedings of the annual meeting, the constitution and by-laws, and the papers presented at such meeting shall be published at the discretion of the Executive Committee in the regular publication or in such other form as the Executive Committee may decide best meets the needs of the membership of the Society.
2. The payment of annual dues for any fiscal year entitles the member or associate to receive without further charge the regular publication of the Society for that year.
3. The Executive Committee may authorize the printing of special publications to be financed by the Society from its general, publication or special funds and offered for sale to members and associates in good standing at not less than the cost of publication and distribution.

III

A—Regional Sections, Technical Divisions, and Affiliated Societies

1. Regional sections of the Society may be established provided the members of such sections are members of the Society and shall perfect an organization and make application to the Executive Committee. The Executive Committee shall submit the application for action first by the Business Committee and second to the Society for a letter ballot as for a constitutional amendment, and provided that the Society may revoke the charter of any regional section by similar action.
2. The Executive Committee may arrange for the affiliation with the Society of duly organized groups or societies, which by object, aims, constitution, by-laws. or practice are developing the study of geophysics or petroleum technology In like manner, the Executive Committee may arrange conditions for dissolution of such affiliations. Affiliation with the Society need not prevent affiliation with other scientific societies. Members of affiliated societies who are not members of the Society, shall not have the privilege of advertising their affiliation with the Society on professional cards or otherwise, but shall be entitled to receive the regular publication of the Society upon payment of a fee equivalent to that charged an associate member.

IV

A—District Representatives

1. The Executive Committee may cause to be elected district representatives from districts which it shall define by a local geographic grouping of the membership. Such districts shall be redesignated and redefined by the Executive Committee as often as seems advisable. Each district shall be entitled to one representative

for each seventy-five members, but this shall not deprive any designated district of at least one representative. The representatives so apportioned shall be chosen from the membership of the district by a written ballot arranged by the Executive Committee. They shall hold office for two years, their term of office expiring at the close of the annual meeting. In so far as possible, these two-year terms shall be overlapping.

V

A—Business Committee

1. The Executive Committee may institute a Business Committee to act as a council and advisory board to the Executive Committee and the Society. This Committee shall consist of the Executive Committee, the Prior Past President, and the district representatives. Favorable action by the Business Committee shall consist of a favorable two-thirds vote. The Secretary-Treasurer shall act as Secretary of the business meeting. Members of this Committee may vote in person, by proxy, or in writing. The Business Committee shall meet the day before the annual meeting at which time proposed changes in the constitution or by-laws may be considered, all old and new business shall be discussed, and recommendations may be voted for presentation at the annual meeting.

VI

A—Amendments

1. These by-laws may be amended by favorable vote of the Business Committee, providing that such changes have been recommended and legality approved by the Executive Committee. Such amendments shall be published in the next regular number of the recognized organ of the Society.